The Kashmir Earthquake of October 8, 2005

A Quick look Report

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1. EXECUTIVE SUMMARY

At 8:50 am Pakistan Standard Time on October 8, 2005, an earthquake of magnitude M_w 7.6 shook northern Pakistan and the Kashmir region. With over 70,000 dead, more than 80,000 injured, and more than two million homeless, the earthquake ranks amongst the worst natural disasters in the history of Pakistan and the Indian subcontinent. According to early estimates (WB-ADB, 2005), the total cost of reconstruction of the damaged infrastructure and rehabilitation is in excess of five billion dollars in direct losses.

The Mid-America Earthquake Center and Rice University with assistance from the Higher Education Commission of Pakistan, and several other organizations, dispatched an earthquake field reconnaissance team to assess the damage, collect data, and derive lessons from the damaging earthquake. Two main objectives were considered in the assembly and dispatch of the field reconnaissance team. These are: (i) gain a first hand experience of the impact of the earthquake and lessons to be learned pertinent to consequence-based earthquake risk management, and (ii) explore and identify avenues of collaboration for long-term earthquake preparedness encompassing research, education, and design code development.

This Quicklook report presents first hand observations, summarizes data collected from various sources in Pakistan and includes early analysis of the available strong-motion records. It provides a brief background on the seismo-tectonic setting of the region, offers preliminary observations on damage to the built infrastructure, reviews socio-economic consequences of the earthquake, and outlines early thoughts on reconstruction priorities and long-term disaster planning. It is stressed that the statistics quoted in the report are preliminary and not universally accepted.

A review of the earthquake history of the area confirms that the Kashmir earthquake, though large by normal standards, is considered 'moderate' when viewed in the context of earthquake generation potential of the India-Tibet subduction region. Moreover, theoretical studies indicate that the energy stored along the Himalayan arc suggests a high probability of several massive earthquakes of magnitude > 8.0 in the future. Strong-motion data from the affected region conforms to attenuation relationships for subduction zones, thrust mechanisms earthquakes derived from other regions. Correlative analyses of a highly rigid bridge in the epicentral zone served as a point of reference for the peak ground parameters inferred from attenuation relationships. Based on the available data, contour maps for peak ground acceleration in the horizontal and vertical directions are derived, pending further confirmation. A suite of records from previous earthquakes, selected on the basis of mechanism and peak ground parameters, is proposed for future studies.

The structural damage observed is expected, owing to the poor quality of construction of traditional housing and modern RC structures not designed to resist earthquake action. It should also be noted that preliminary analysis of a set of strong-motion records from Abbottabad indicated that shaking in the epicentral region was severe; comparable to shaking in previous major damaging earthquakes in Turkey, the USA and Japan. Since design wind loads are rather modest in the regions, even engineered structures are not expected to resist significant lateral loads since they were not designed to resist significant wind loads. The MAE Center-Rice University Team concluded that engineered structures were fairly well constructed, and cases of failure were due mainly to layout defects, such as soft ground storey, short columns, irregular plans and elevations, as well as lack of maintenance on a few cases. Bridge structures on the whole responded well to the earthquake with only very few cases of heavy damage, and fewer cases of collapse.

The earthquake emphasized the impact of slope failures, site response and the effect of topography. Tens of miles of slope failures were observed, and many other slopes remain precariously unstable awaiting a triggering event. At the time of printing this report, news has emerged that such an event has indeed occurred, with a magnitude of 6.7. With regard to site response features, in at least two cases, in Balakot and Muzaffarabad, significant ridge effects were observed, leading to totally disproportionate levels of damage, relative to other regions and the severity of shaking expressed by the peak ground parameters.

Lifelines behaved reasonably well, with pockets of severe damage that has had a significant short-term effect on search and rescue operations in the region. The impact on healthcare and education has been severe. Nonetheless, recovery has been more rapid than observed by members of the MAE Center-Rice University Team who have studied several previous earthquakes worldwide. The response of Government organizations, the Pakistani Army and private companies was impressive, as evidenced by the rapid return to a manageable situation and effective distribution of national and international aid. The rapid move from search and rescue to emergency management and to planning for the reconstruction phase was deemed by the Team to be admirable.

It is too early to draw conclusive lessons that are sufficient to steer the reconstruction effort and the necessary planning for future earthquakes and other potential disasters. However, it is clear that priorities should be set rather cautiously in order to use the devastating impact of the Kashmir earthquake in as positive a framework as possible, to renovate the built environment based on rigorous redesign and reconstruction criteria, benefiting from available technologies, whilst adapting them to Pakistani realities and circumstances. The Field Mission Team advises caution in selecting materials, systems and experts to aid in the reconstruction efforts, and recommends drawing a global approach balancing short- and long-term needs, recovery and planning for future earthquakes, critical and popular facilities (e.g. hospitals, schools, power plants, etc as critical facilities, versus sports and recreational facilities, convention centers, etc as popular facilities). It is also critical to rapidly develop design and construction guidance that is based on rigorous and confirmed engineering knowledge, whilst maintaining simplicity and ease of application. Finally, filtering of overseas knowledge and experience is another critical issue, in order that homogeneous and nationally-applicable retrofitting approaches and emergency planning measures are adopted and applied uniformly in Pakistan. Preliminary recommendations are included at the end of this report.

2. OVERVIEW OF THE EARTHQUAKE AND LOSSES

A powerful earthquake of magnitude M_w 7.6 shook Kashmir and the adjoining northern part of Pakistan on October 8, 2005 at 8:50 a.m. local time. With its epicenter estimated at about 10 miles from Muzaffarabad, the administrative capital of Azad Jammu and Kashmir (AJK) and 65 miles NNE of Islamabad, the capital of Pakistan as shown in Figure 2.1, the earthquake caused the most damage in AJK and the North West Frontier Province (NWFP) of Pakistan. Some losses were reported in the Indian controlled part of Kashmir and Southern Afghanistan.

The earthquake nucleated in the active tectonic region of the northern part of the Indian subcontinent. The South Asian plate comprising Pakistan, India and Bangladesh is continuously moving northward, colliding with and subducting under the Eurasian plate, thus triggering earthquakes and forming the Himalayan mountain ranges. Because of their low frequency, the historical memory and awareness about these earthquakes appears to have faded. The indigenous practice of lighter weight, timber-laced construction has gradually given way to relatively more massive masonry and reinforced concrete construction which provides adequate protection against harsh elements but is often poorly constructed to withstand strong earthquakes. The current building code and regulatory requirements for safety against earthquakes are outdated and seldom enforced. The existing seismic design guidelines (not an enforceable code) are based on the 1970s Uniform Building Code and include an incomplete and non-rigorous seismic zoning map. The guidelines are not mandatory.

Figure 2.1 General location of the 8 October 2005 Kashmir earthquake

Several local and international organizations, including the World Bank and the Asian Development Bank, have surveyed the earthquake damage (e.g. WB-ADB, 2005). Table 2.1 summarizes the impact in terms of loss of life and damage to housing. Field observations and the statistics given in Table 2.1 suggest damage to a broad range of construction which included both engineered and non-engineered structures. The high economic losses associated with this earthquake mirror the recorded extensive damage and the loss of human life.

Table 2.1 Overall impact of the earthquake on the population (WB-ADB, 2005)

Indicator	Latest Estimate
Area Affected	30,000 sq km
Population Affected	Between 3.2 million and 3.5 million
Deaths	73,000
Injured	79,000
Houses	400,153 (damaged and destroyed)
Families affected	500,000 (seven persons per family on average)

Notes: The death toll has been revised upwards to more than 80,000

The exact magnitude of the economic impact of this earthquake remains yet to be fully determined but the current estimates, summarized in Table 2.2, suggest that the direct economic cost is over $5 billion. This estimate does not account for loss of direct and indirect economic activity, such as business interruption and loss of market shares for Pakistani products.

Table 2.2: Economic cost of the earthquake (WB-ADB, 2005)

Category	US $ M	US $ M
Relief		1,092
Death and Injury Compensation		205
Early Recovery		301
Restoration of Livelihoods		97
Reconstruction		3,503
Of which short term Reconstruction	450	
Of which Medium/Long term Reconstruction	3053	
Total		5,198

The losses in the North West Frontier Province (NWFP) and Azad Jammu and Kashmir (AJK) are given in Table 2.3. It is estimated that 72,705 people were killed and 68,157 were injured as a consequence of the earthquake[1]. Over 72,019 buildings were completely destroyed and additional 182,886 buildings were severely damaged.

Table 2.3 Overall numbers of losses caused by Kashmir Earthquake for NWFP and AJK areas, as of Nov. 12 (AJK: http://www.ajk.gov.pk, NWFP: WB-ADB)

District	Life		Buildings		Damage length of Road (km)
	Dead	Injured	Fully D.	Partially D.	
North West Frontier Province (NWFP)					
Shangla	423	957	15,880	11,087	405
Manshera (Balakot)	24,511	30,585	32,293	43,925	671
Kohistan	661	639	4,504	18,737	396
Abbottabad	515	1,730	7,267	27,813	306
Batagram	3,232	3,279	29,015	8,841	284
Sub-Total NWFP	**29,342**	**37,190**	**88,959**	**110,403**	**2,062**
Azad Jammu Kashmir (AJK)					
Neelum	447	1,013	3,692	8,991	-
Muzaffarbad	33,724	21,374	115,211	17,209	1237
Bagh	8,157	6,644	48,365	18,736	461
Rawalakot	1,025	1,909	15,362	25,770	667
Sudhnoti	4	16	430	1,777	-
Mirpur	6	11	0	0	-
Sub-Total AJK	**43,363**	**30,967**	**183,060**	**72,483**	**2,365**
Total	**72,705**	**68,157**	**272,019**	**182,886**	**4,427**

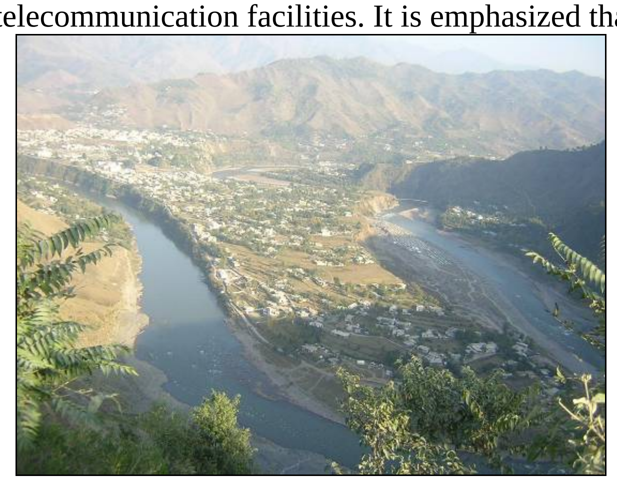
[1] As of November 12, 2005

Table 2.4 provides detailed damage statistics for buildings. Medical facilities and schools were among the hardest hit structures. Debris from the collapsed buildings is estimated to be more than 50 million tons. It is estimated that about 40% of telecommunication exchanges and 15% of telephone lines in AJK and 30% of exchanges and 8% of lines in NWFP were disrupted. Approximately 30-40% of water supply is believed to have been affected as a result of the earthquake in both AJK and NWFP (WB-ADB, 2005). Power distribution networks and fuel supplies were also severely impacted. As a result of this earthquake, approximately one third of primary and tertiary roads and one fourth of secondary roads in the two provinces became impassable, mostly from landslides, thus hampering the immediate relief effort.

Table 2.4 Statistics for damaged buildings caused by Kashmir Earthquake for NWFP and AJK areas, Nov 12 (AJK: http://www.ajk.gov.pk, NWFP: WB-ADB)

District	Housing		Educational Institutes		Medical Facilities		Other Government Buildings		MISC Structures (Shops, Mosques, etc)		Sub-Total	
	Full	Partial	Full	Partial	Full	Partial	Full	Partial	Full	Partial	Full	Partial
North West Frontier Province (NWFP)												
Shangla	15,661	10,821	206	247	13	19	-	-	-	-	15,880	11,087
Manshera	31,323	43,282	935	624	35	19	-	-	-	-	32,293	43,925
Kohistan	4,350	18,395	154	320		22	-	-	-	-	4,504	18,737
Abbottabad	6,961	27,051	295	736	11	26	-	-	-	-	7,267	27,813
Batagram	28,712	8,656	268	180	35	5	-	-	-	-	29,015	8,841
Sub-Total	**87,007**	**108,205**	**1,858**	**2,107**	**94**	**91**	-	-	-	-	**88,959**	**110,403**
Azad Jammu Kashmir (AJK)												
Neelum	3,692	7,215	0	75	0	9	0	2	0	1,690	3,692	8,991
Muzaffarabad	108,157	17,120	929	0	103	0	77	89	5,945	0	115,211	17,209
Bagh	47,619	18,226	511	240	49	40	186	76	0	154	48,365	18,736
Rawalakot	15,086	25,405	125	275	16	19	78	71	57	0	15,362	25,770
Sudhnoti	429	1,719	1	54	0	2	0	0	0	2	430	1,777
Mirpur	0	0	0	0	0	0	0	0	0	0	0	0
Sub-Total	**174,983**	**69,685**	**1,566**	**644**	**168**	**70**	**341**	**238**	**6,002**	**1,846**	**183,060**	**72,483**
Total	**261,990**	**177,890**	**3,424**	**2,751**	**262**	**161**	**341**	**238**	**6,002**	**1,846**	**272,019**	**182,886**

Muzaffarabad, the administrative capital of AJK with a population of over one million was the single most affected city with more than 23,000 killed. The city experienced extensive damage to private homes, public buildings, hospitals, schools, road networks, bridges, and telecommunication facilities. It is emphasized that statistics are continuously being updated.


(a)

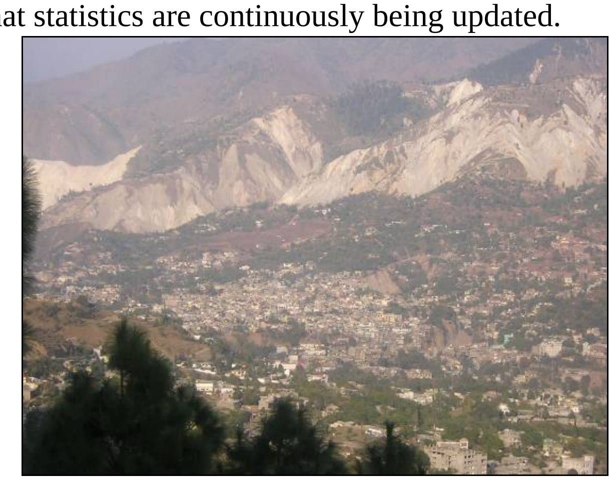

(b)

Figure 2.2 Muzaffarabad, (a) view from the south and (b) residential areas in the north (note landslides in (b))

The MAE Center-Rise University (MCRU) team visited the most severely damaged areas in both Muzaffarabad and Balakot. The field visit details, composition of the team, and a list of organizations and individuals the team interacted with are provided in Appendix A. Figure 2.3 shows the travel route of the team as recorded through the GPS travel log.

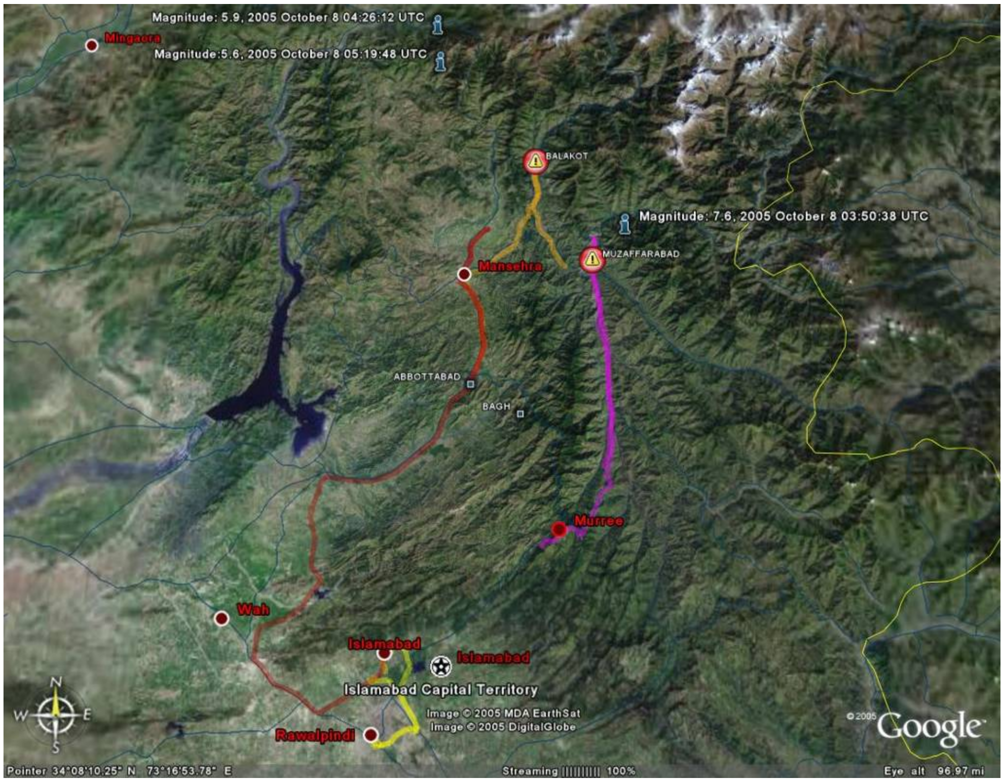


Figure 2.3 Map of northern Pakistan showing the travel route and the major cities visited by the MCRU team. Thick color lines represent the GPS log of the route.

The subsequent sections of this Quicklook report provide more detailed information and discussion on the regional seismo-tectonic setting, performance of the built infrastructure, and geotechnical observations, as well as the social and economic impact of the earthquake.

3. SEISMOLOGICAL FEATURES

3.1 TECTONIC SETTING

The collision of India with Asia has resulted in the flexural deformation of the Indian sub-continent with a half-wavelength of approximately 670 km, giving rise to stresses that are responsible for many of the earthquakes in central India. The largest of India's earthquakes, however, occur on the northern boundary of the Indian plate where it descends beneath southern Tibet (Bilham and Ambraseys, 2005).

The Kashmir earthquake, which affected Kashmir, Jammu and the North-West Frontier Province of Pakistan, is associated with the great plate boundary region as shown in Figure 3.1, where the Indian Plate is subducting under the Asian Plate. The tectonic movement in the region is responsible for the creation of the Himalayan mountain ranges through compressive and bending stresses. The subduction mechanism has triggered a few great and several intermediate earthquakes in a band of about 50-80 km width and an arc length of about 2500 kms (Bilham, http://cires.colorado.edu/~bilham/). The recent event lies at the western tip of the active subduction Himalayan belt.

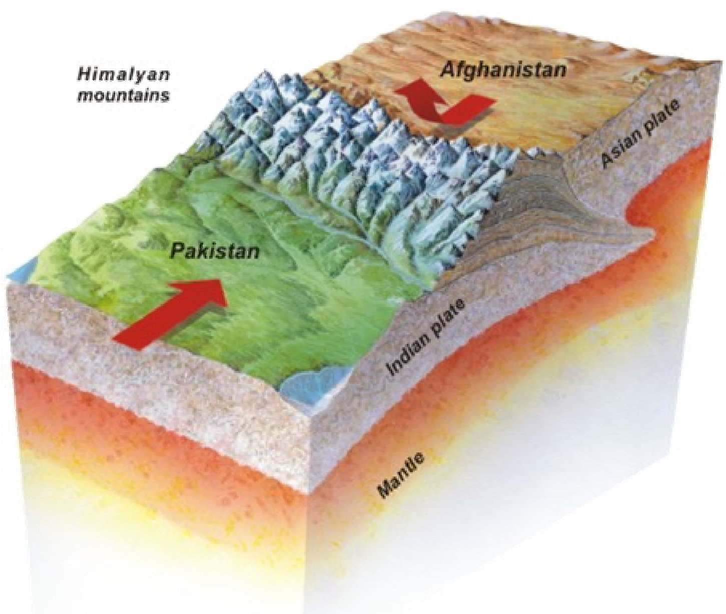


Figure 3.1 Global tectonic setting of the Kashmir earthquake within the Indian-Asian plates subduction region
(note: credit for this graphic is unknown, since it is third-hand)

Table 3.1 lists historical earthquakes in the region with those close to the location of the recent Kashmir earthquake highlighted in red.

Table 3.1 Historical earthquakes associated with the subduction region (Bilham and Ambraseys, 2005)

Event	*Mw*	Lat. (°N)	Long. (°E)	Year	Month	Day	Moment	Cum moment	Rate (mm/yr)
Lo Mustang	8.2	29.5	83	1505	June	6	2.14E + 28	2.14E + 28	79.2
Srinagar	**7.6**	**33.5**	**75.5**	**1555**	**September**		**2.69E + 27**	**2.41E + 28**	**8.1**
Uttarpradesh	7.5	30	80	1720	July	15	1.91E + 27	2.60E + 28	2.2
Uttarpradesh	8.1	31.5	79	1803	September	1	1.51E + 28	4.11E + 28	2.5
Nepal	7.7	27.7	85.7	1833	August	26	3.80E + 27	4.49E + 28	2.5
Srinagar	**6.4**	**34.1**	**74.6**	**1885**	**May**	**29**	**4.27E + 25**	**4.50E + 28**	**2.2**
Kangra	7.8	33	76	1905	April	4	6.03E + 27	5.10E + 28	2.3
Bashahr	6.4	31.5	77.5	1906	February	27	5.13E + 25	5.10E + 28	2.3
Uttaranchal	7.3	29.9	80.5	1916	August	28	8.32E + 26	5.19E + 28	2.3
Uttaranchal	6.5*	30.3	80	1926	July	26	6.00E + 25	5.19E + 28	2.3
Nepal-Bihar	8.1	27.6	87.1	1934	January	15	1.82E + 28	7.01E + 28	3.0
West Nepal	7*	28.5	83.5	1936	May	7	1.00E + 27	7.11E + 28	3.0
Shillong	6.8	27	92	1941	January	21	5.01E + 25	7.12E + 28	3.0
Uttaranchal	6.5*	30.3	80	1945	June	4	6.00E + 25	7.12E + 28	3.0
Chamba	6.3	32.8	76.1	1945	June	22	3.16E + 25	7.13E + 28	3.0
Assam	7.3*	28.8	93.7	1947	July	29	8.30E + 26	7.21E + 28	3.0
Assam-Tibet	8.5	28.7	96.6	1950	August	15	5.62E + 28	1.28E + 29	5.3
Anantnang	**5.6**	**33.6**	**75.3**	**1967**	**February**	**20**	**3.16E + 24**	**1.28E + 29**	**5.1**
West Nepal	6.5*	29.6	81.1	1980	July	29	6.00E + 25	1.28E + 29	5.0
Uttarkashi	6.8*	30.8	78.8	1991	October	21	1.80E + 26	1.29E + 29	4.8
Chamoli	6.4*	30.5	79.4	1999	March	29	5.20E + 25	1.29E + 29	4.8

*Indicates magnitude adapted from other catalogues.

The Kashmir earthquake fits the pattern and fills a gap identified through GPS measurements and long-term geodetic observations of the Himalayan arc. Its association with a particular fault is still an issue of debate. This is typical of collision regions, as opposed to strike-slip or normal faulting where the causative fault is often well-delineated. Pending further investigations, the most recent interpretation of the fault mechanism and local fault association is discussed in the next section.

3.2 Macro-Seismic Data and Fault Mechanism

The earthquake struck at 8:50:40 am local time (03:50:40 coordinated universal time UTC) on October 8, 2005. The USGS magnitude is M_w=7.6, and the location coordinates are 34.493N-73.629E, with a focal depth of 26 kms (16.2 miles). A very large number of aftershocks were recorded, reaching more than 1000 in the first few weeks of magnitudes up to 6. A definitive identification of surface manifestations of the fault rupture has not been possible thus far, and is unlikely to occur in the future. It is likely that the fault rupture is ‘blind’, i.e. it stopped a few kilometers short of the surface. It is the opinion of the MCRU team that the fractures reported in the literature are secondary and not associated directly with the fault rupture. Moreover, the extensive land sliding observed is also not directly associated with the fault rupture. Satellite imaging (COMET; http://comet.nerc.ac.uk/) provided a reasonable estimate of the location of the fault and its extent by mapping the shortening on the surface. The presumed fault trace is shown in Figure 3.2. The direction of the fault, being N27E to N30E, is confirmed from more than one source. The length of the rupture is reported by Harvard Seismology to be about 90 km, with a width of about 50 km. The fault plane dips about 37 degrees and the mechanism is mostly thrust (Harvard and others fault plane solution shows a mildly oblique fault mechanism). The average slip is between 2-4 meters, confirmed from several sources (COMET, Harvard, Bilham, 2005).

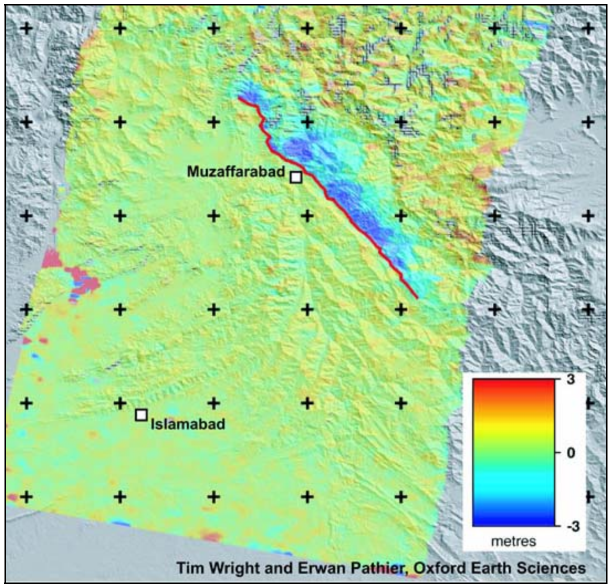


Figure 3.2 Location and extent of fault rupture (COMET)

The MCRU team did not undertake a systematic damage assessment survey for intensity assessment. However, the team estimates that many places in Muzaffarabad suffered intensity MMI to X, contrary to reports currently available where lower intensities were reported. MMI to X is described as: *Most buildings and their foundations are destroyed. Some bridges are destroyed. Dams are seriously damaged. Large landslides occur. Water is thrown on the banks of canals, rivers, lakes. The ground cracks in large areas. Railroad tracks are bent slightly*. The same intensity, with a tendency towards XI, is assigned by the team to Balakot, where semi-engineered buildings collapsed en masse, and some well engineered structures, such as hotels, were destroyed. Intensity XI is described as: *Most buildings collapse. Some bridges are destroyed. Large cracks appear in the ground. Underground pipelines are destroyed. Railroad tracks are badly bent*. Absence of evidence should not be construed as evidence of absence. Therefore, the absence of railroads and collapsed bridges should not lead to under-estimating the intensity. Because of the rugged topology, the epicentral region has a rather sparse network of bridges. These bridges are either very slender deck structures as is typical of suspension bridges, or have massive reinforced concrete short span girders, both of which are less vulnerable to earthquakes than the medium-to-large span reinforced concrete bridges.

A closer examination of the rupture region indicates an axis running through Muzaffarabad and Balakot, as shown in Figure 3.3. This zone overlies the complex faulting mechanism shown in Figure 3.4. The latter figure explains the local faulting mechanism while linking it to the global tectonic setting by showing the Indian plate dipping under the Asian plate, through a band of complex secondary faults.

It should be noted that much of the information available on the region under consideration is gleaned from relatively recent instrumentation records. It is therefore highly likely that the seismicity of the region is in general under-estimated, or at least mis-represented. In Ambraseys and Douglas (2004) it is shown that historical data is subject to interpretation and is on the whole inadequate.

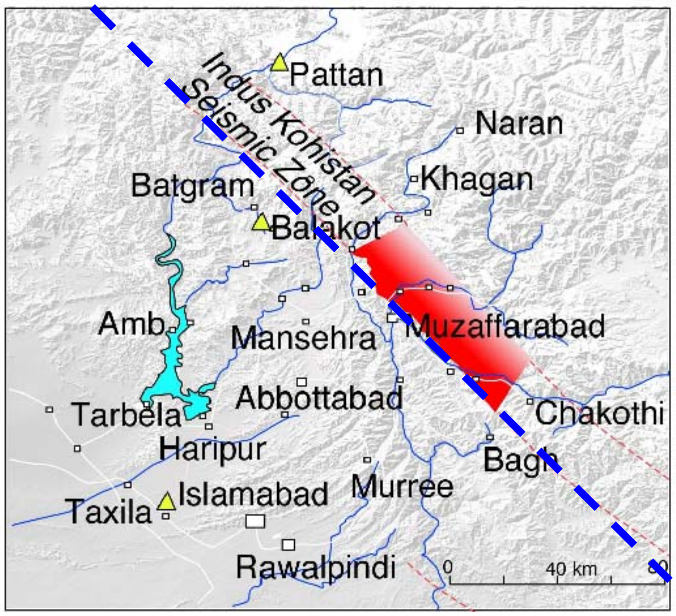


Figure 3.3 Rupture region (adapted from http://cires.colorado.edu/~bilham/Kashmir%202005.htm)

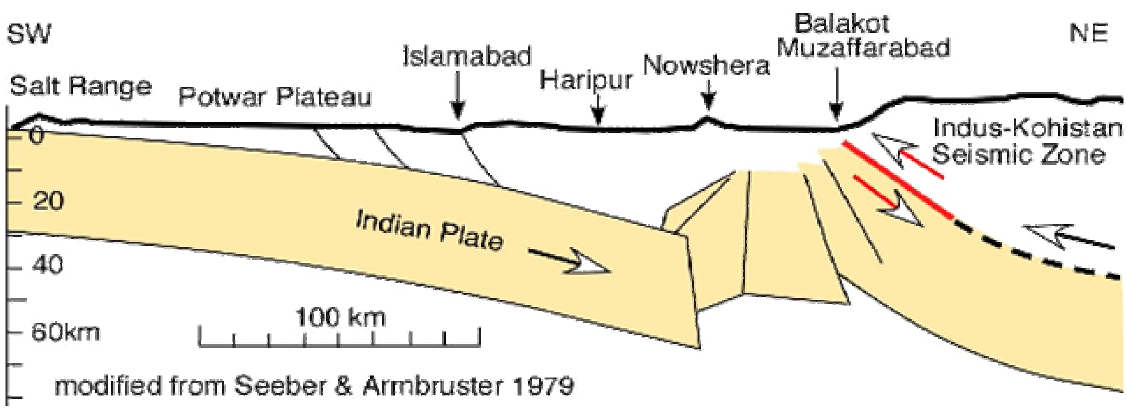


Figure 3.4 Cross section approximately along the blue line in the previous figure (as above)

3.3 Strong Ground Motion

At the time of writing this report, only three strong-motion acceleration records (Mahmood, 2005) were made available to the MCRU team, and none are from the heavily damaged regions of Balakot and Muzaffarabad. Three records, each with three components, are available for Nilore, Murree and Abbottabad (Figure 3.5). The three records are reproduces in Figure 3.6, Figure 3.7, and Figure 3.8. Their elastic and inelastic spectra are given in Figure 3.9. In each plot, elastic (5%) and ductility 2, 4 and 6 spectra are shown for the higher PGA of the two horizontal components.

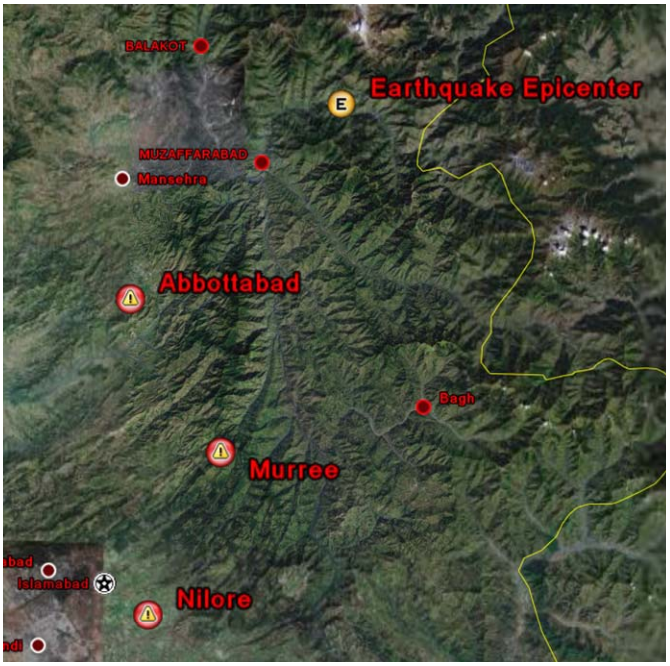


Figure 3.5 Location of recoded data

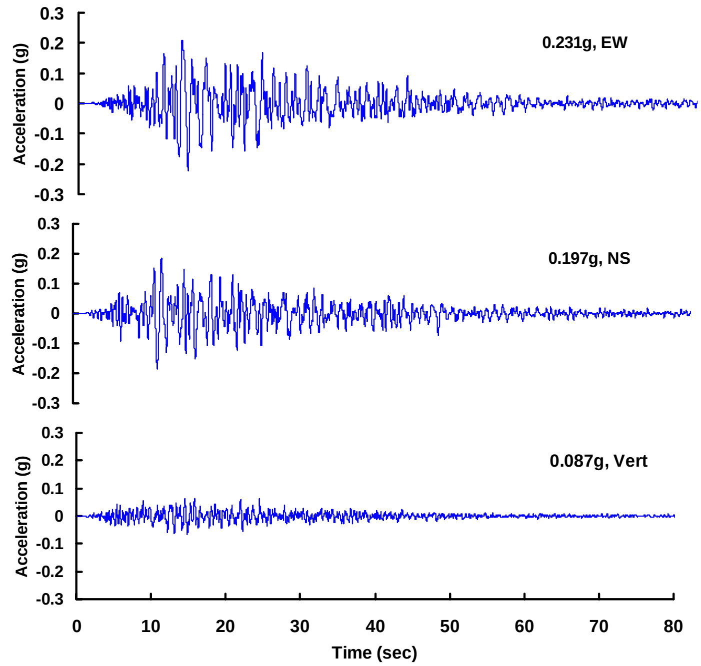


Figure 3.6 Strong Motion Records at Abbottabad

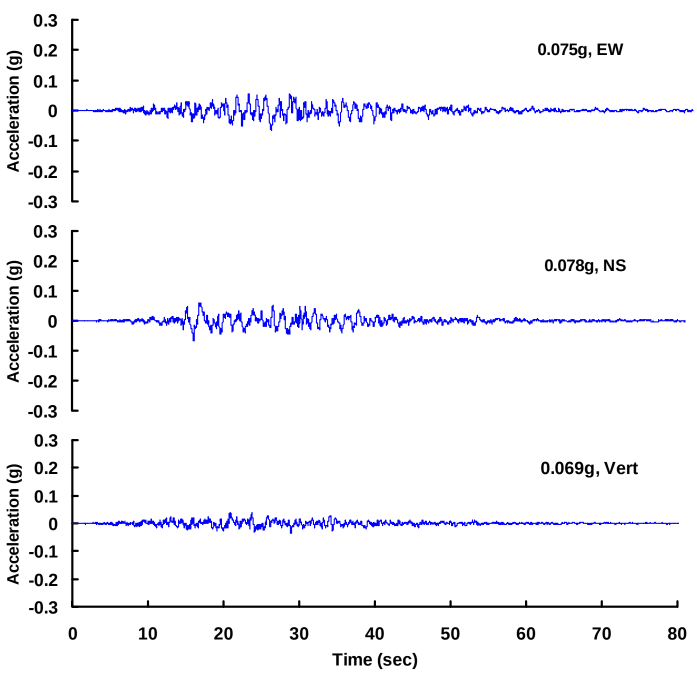


Figure 3.7 Strong Motion Records at Murree

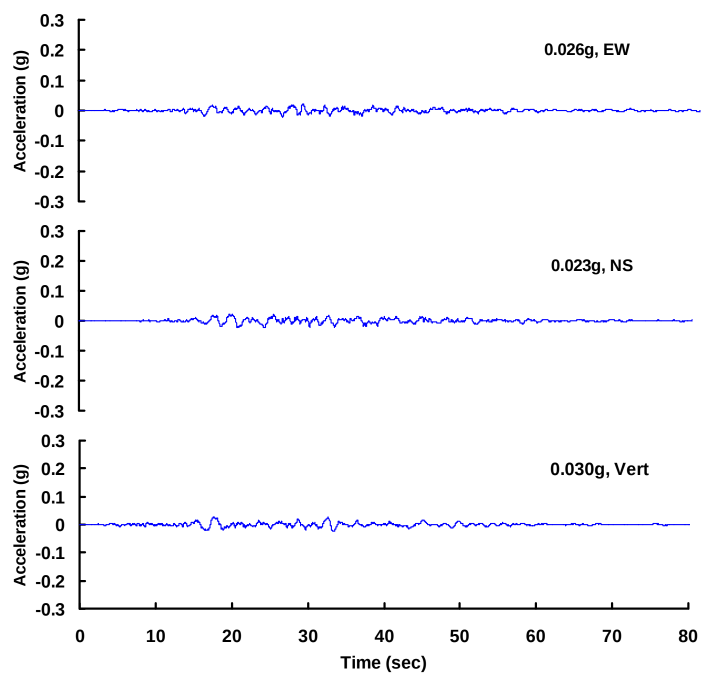
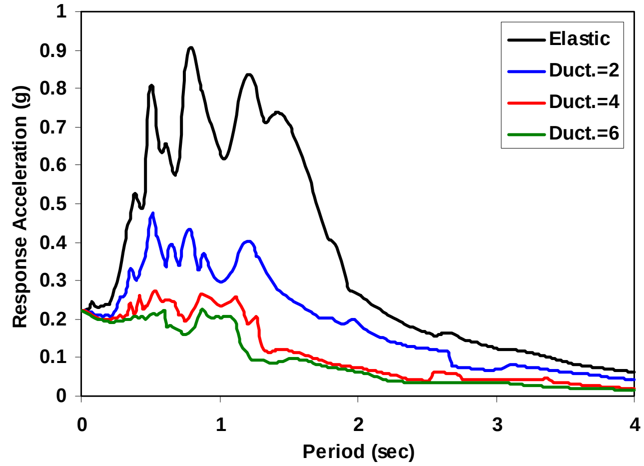
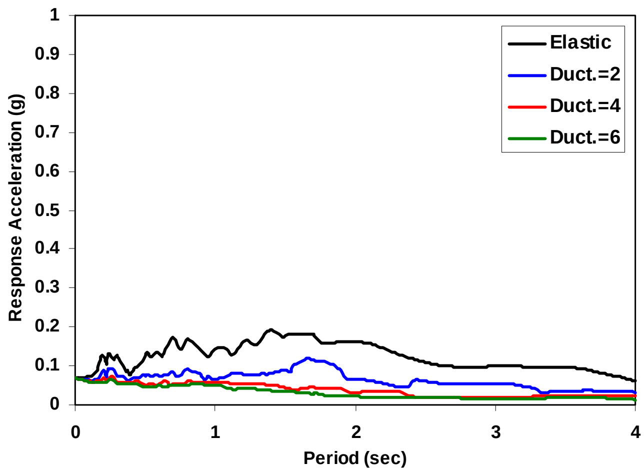


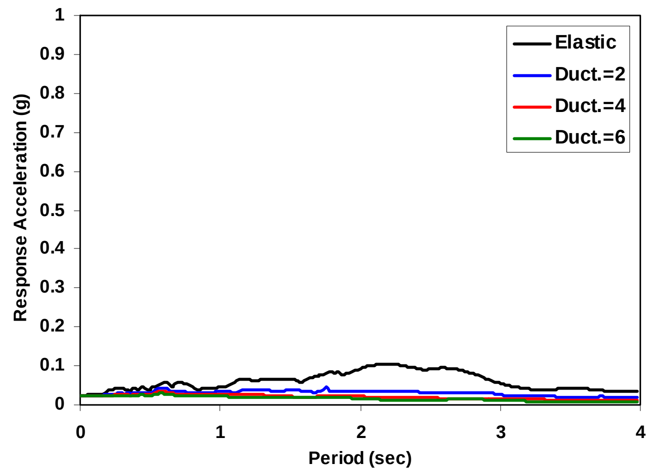
Figure 3.8 Strong Motion Records at Nilore



(a) Abbottabad, EW component



(b) Murree, NS component



(C) Nilore, NS component

Figure 3.9 Spectra for horizontal component of each record

The signal from Abbottabad is the most usable of the three available records, since it is obtained from an area where significant damage has occurred. The two other records are rather weak. It is important to note that scaling the Nilore and Murree records is not advised. There are certain features in their spectra, namely the relatively high amplification in the long period range (up to 3 seconds period), that would be exceptionally demanding on long period structures if the records are scaled to render them useable in back-analysis. Attention is hereafter focused on the Abbottabad record. The 5% elastic spectrum shows a relatively broad range of high amplification, from 0.4 to 2.0 seconds. The highest amplification is about 4.0. This is compared to the value of 2.6, which is the 84 percentile amplification factor given by Newmark and Hall (1982), thus indicating the relative severity of the Abbottabad record. The range of periods corresponding to high amplifications is also unusual, extending to 2.0 seconds. Such a feature would result in relatively high demand imposed on both short and intermediate-long period structures. The constant ductility spectra shown in Figure 3.9 indicate rather low strength demand for highly ductile structures (of ductility of 4.0 or more), and average demands for intermediate ductility structures (of ductility around 2.0). Table 3.2 contrasts amplification factors from the Abbottabad acceleration signal with records from the Northridge (USA, 1994), Hyogo-ken (Japan, 1995) and Kocaeli (Turkey, 1999) earthquakes.

Table 3.2: Acceleration response (proportional to force demand) for ductility=2, at given periods, in %g

Earthquake-Record	T=0.5 s	T=1.0 s	T=1.5 s	T=2.0 s
H-K Nambu JMA	1.5	0.8	0.4	0.2
Northridge Sylmar	1.4	0.5	0.6	0.5
Northridge Arleta	0.3	0.25	0.15	0.05
Kocaeli Yarimca	0.3	0.3	0.22	0.18
Kashmir Abbottabad	0.45	0.30	0.26	0.19

Table 3.2 shows that the Abbottabad record is less demanding than the known rich records of JMA Kobe and Sylmar Northridge for short periods, but close to them in the long period range. It is as demanding as the Yarimca record, known to have devastated the area hit by the earthquake of August 1999 (Elnashai, 2000). Taking into account how far Abbottabad is from the epicentral region, the overall impression the above brief review yields is that the built environment in the region affected was hit by very powerful strong ground motion. Further analysis will be provided in the full MAE Center report on the Kashmir earthquake.

The MCRU team has also obtained peak ground acceleration data at two sites (Khan, 2005), namely Tarbela Dam and Barotha Power Complex. The peak ground accelerations are as shown below:

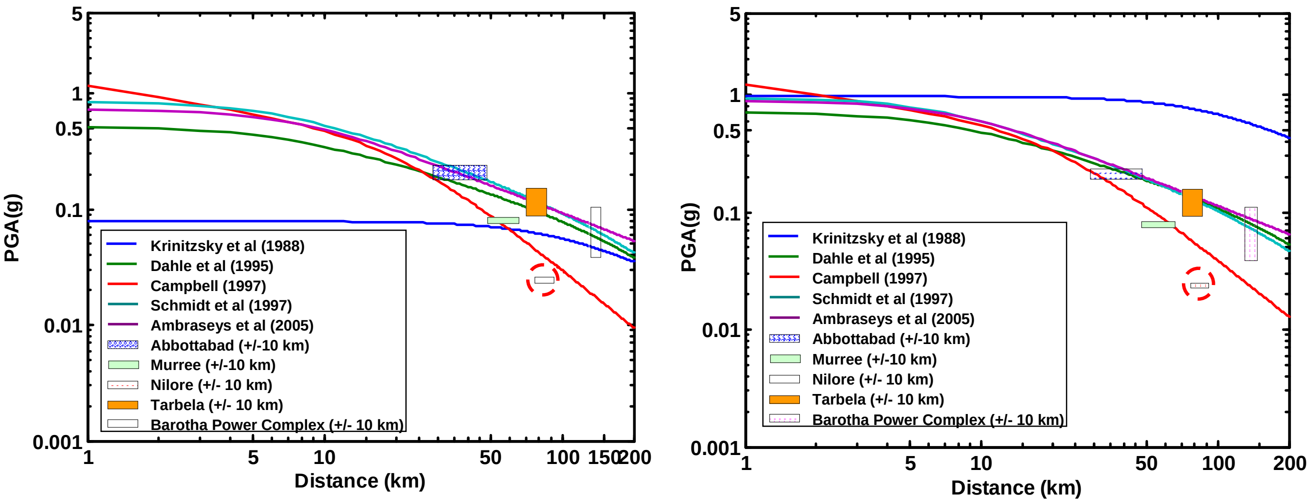
Tarbela Accelerograph Record:
MED Crest Station 45+12: 0.14g
P/H Plunge Pool on Rock Sta 63+42: 0.10g
MED Crest Station 83+42: 0.12g
AD-2 Crest Station 8-0: 0.16g
AD-1 Crest Station 22+50: 0.10g
AUX Spillway SMA: 0.10g

Barotha Power Complex Accelerographs record:
Power Complex base: 0.04g
Power Complex top: 0.11g

To provide records for back-analysis in areas where no recordings are known to exist, the available peak ground accelerations from the five sites were used to select attenuation relationships that may then be used to derive ground parameters maps for the region affected by the earthquake. The criteria for selecting the attenuation relationships to be investigated were (i) subduction zones, thrust mechanisms, (ii) large magnitude, and (iii) a large and uniformly processed data base. The candidate attenuation relationships are given in Table 3.3 below alongside predictions for the various important sites. The relationships are plotted for the Kashmir earthquake characteristics for the horizontal component, assuming stiff and soft soil. The plots are shown in Figure 3.10. The peak ground acceleration values from Tarbela, Barotha, Abbottabad, Nilore and Murree are also shown along with the distance error bars of +/- 10 km. Distances are measured from the presumed fault zone described previously. Based on the fidelity of prediction of the peak ground acceleration values, two attenuation relationships are feasible; Campbell (1997) and Ambraseys and Douglas (2005). The former tends to give lower estimates than the latter. Taking into account that the pga at Nilore is probably affected by the dimensions of the raft where the instrument was anchored, and taking a conservative approach, the relationship of Ambraseys and Douglas is selected. It is noteworthy that the relationship of Campbell (1997) would give marginally higher pga in the near-source region. This observation should be considered by analysts when using and scaling the records selected in this report. Finally it is noteworthy that the vertical ground motion is very well predicted by the selected attenuation relationship, an observation that supports the effect of the raft foundation mentioned above.

Table 3.3: Prediction of horizontal peak ground acceleration for each attenuation relationship

Location (distance from fault)	Krinitzsky et al (1988)		Dahle et al (1995)		Campbell (1997)		Schmidt et al (1997)		Ambraseys et al (2005)	
	Stiff	Soft	Stiff	Soft	Stiff	Soft	Stiff	Soft	Stiff	Soft
Tarbela (80 km)	0.061	0.757	0.094	0.130	0.042	0.055	0.114	0.127	0.111	0.135
Barotha P. C. (140km)	0.046	0.563	0.057	0.079	0.017	0.023	0.065	0.072	0.071	0.087
Muzaffarabad (4 km)	0.079	0.968	0.458	0.635	0.720	0.800	0.751	0.835	0.659	0.805
Balakot (10 km)	0.078	0.964	0.345	0.478	0.471	0.548	0.531	0.591	0.486	0.594
Abbottabod (39 km)	0.073	0.903	0.16	0.221	0.124	0.155	0.21	0.234	0.194	0.237
Islabamad (98 km)	0.056	0.692	0.079	0.110	0.031	0.04	0.094	0.104	0.094	0.115

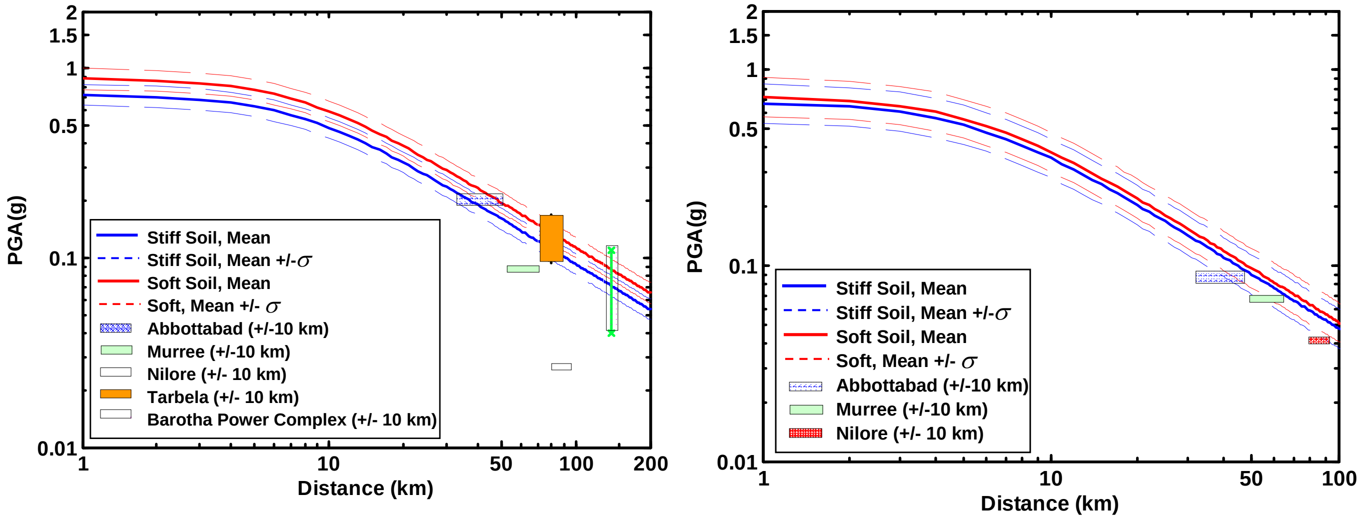


(a) PGA prediction for stiff soil (b) PGA prediction for soft soil

Figure 3.10 Prediction of horizontal peak ground acceleration (bracketed value is suspect)

Note: Record at Nilore (red circle) is response of raft foundation

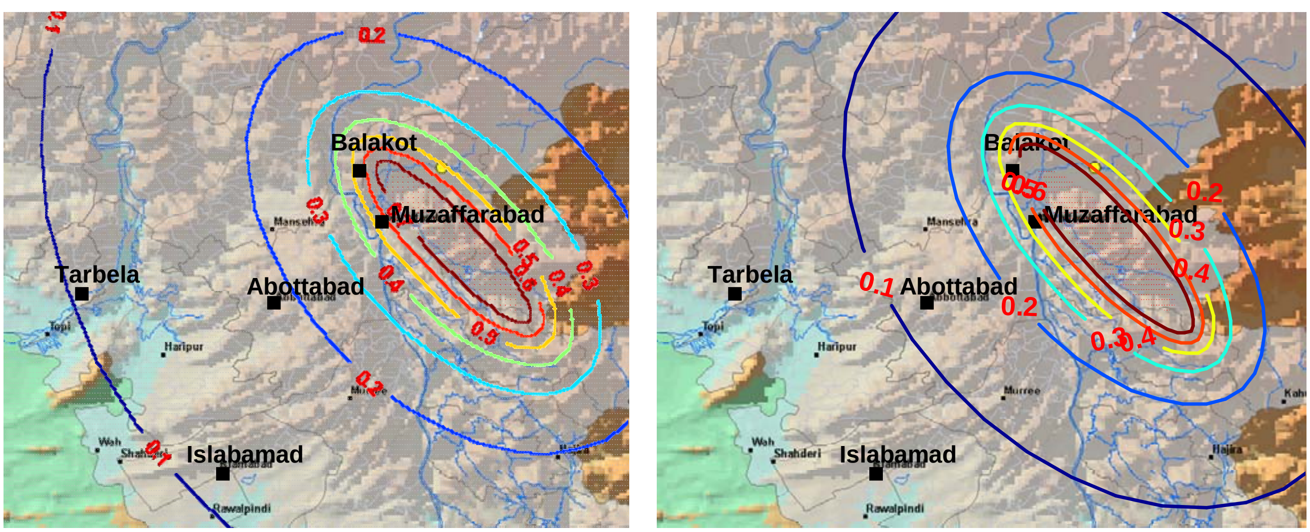
The selected attenuation relationship is plotted with its level of uncertainty as reported by Ambraseys and Douglas (2005), and is shown in Figure 3.11 for stiff and soft soil. Moreover, since thrust mechanisms often lead to high vertical ground motion, with consequential extensive damage (Collier and Elnashai (2001), Papazoglou and Elnashai (1996)), the companion vertical attenuation relationship is invoked, and plotted as shown in Figure 3.11 (b).



(a) PGA prediction for horizontal ground motion (b) PGA prediction for vertical ground motion

Figure 3.11 Prediction of peak ground acceleration using equation by Ambraseys and Douglas (2005)

As a prelude to the back-analysis intended for the full MAE Center report that is currently under development, contour maps for horizontal and vertical ground acceleration in the region affected by the Kashmir earthquake are generated, and shown in Figure 3.12. It is noted that the ground parameter values in the very close vicinity of the fault may be significantly less representative than elsewhere. This is because each earthquake has its own characteristics, fault rupture sequence, direction, and propagation. Therefore, near-source values are indicative only and aid in selecting records for the purposes of back-analysis. As mentioned above, the latter point should be taken into account when scaling records for back-analysis in regions of close proximity to the fault. Values at some distance from the fault, e.g. >10kms, should be reliable due to the good match between the measured pga values and the Ambraseys and Douglas (2005) attenuation relationships.



(a) Contour map for horizontal ground motion (b) Contour map for vertical ground motion

Figure 3.12 PGA Contour maps for the affected region (on the fault trace, accelerations of 1g or higher are possible)

Table 3.4: Selected records for back-analysis, two for each side, based on available information

Location	Earthquake Name	Station Name	Mw	Fault Distance	Soil Type	PGA (g)		
						Long.	Trans.	Verti.
Muzaffarabad (4 km)	Gazli	Gazli	6.7	4 km	soft soil	0.616	0.721	1.288
	Tabas	Tabas	7.4	3 km	stiff soil	0.927	1.103	0.840
Balakot (10 km)	Tabas	Dayhook	7.4	11 km	Rock	0.338	0.386	0.174
	Montenegro	Bar-Skupstina O.	7.05	12 km	stiff soil	0.376	0.363	0.254
	Montenegro	Pertovac-Hotel O.	7.05	12 km	stiff soil	0.455	0.306	0.213
Abbottabad (39 km)	Tabas	Boshroyeh	7.4	34 km	soft soil	0.102	0.087	0.079
	Montenegro	Ulcinj-Hotel O.	7.05	24 km	stiff soil	0.294	0.241	0.458
Islabamad (98 km)	Tabas	Ferdoos	7.4	94 km	stiff soil	0.092	0.102	0.053
	Montenegro	Veliki S. S.	7.05	105 km	alluvium	0.268	0.181	0.046

Gazli (1976, Uzbekistan), Tabas (1978, Iran), and Montenegro (1979, Yugoslavia)

The source mechanism, magnitude and peak ground accelerations obtained thus far were employed to select earthquake records for sites where extensive damage was observed. Table 3.4 lists the selected earthquakes, two for each side with the exception of Balakot, where three records are selected. These records are recommended for use in loss assessment studies for the region, alongside the actual acceleration recordings from Nilore, Abbottabad and Murree. It is stressed that the Nilore record should be used with caution in view of the location of the instrument.

3.4 Implications on Future Earthquake Hazard and needs

The Kashmir earthquake, in a regional setting, is considered to be a moderate earthquake. The region is susceptible to great earthquakes of magnitudes > 8.0. Estimates of slip rates vary considerably, and it is not the objective of this Quicklook report to resolve the differences or re-interpret their underlying assumptions. The most reliable estimates from the authors viewpoint suggest an average slip of ~ 18 mm/year (Bilham and Ambraseys, 2005), averaged over the entire India-Tibet collision zone. The average slip observed in earthquakes in the past 5 centuries amounts to less than 3 mm/year. Whereas other interpretations exist, the most likely outcome of the above is that there are massive earthquakes awaited, nucleating in the Himalayan arc. In the latter publication, it is estimated that four earthquakes of magnitude > 8.4 are required to make up for the slip deficit between GPS-calculated strains, and slip during earthquakes observed from year 1500 to 2000. With the Kashmir earthquake releasing less than 10% of the energy stored in the collision region, many large population centers throughout northern Pakistan and India are exposed to serious seismic risk.

The dearth of strong ground motion records point to the need for a well developed seismic monitoring network of not only the area affected by the recent earthquake, but for all of Pakistan. Moreover, a clearing house should be established to disseminate such data, and other information on the earthquake, to encourage the earthquake engineering community to undertake analysis and assessments, thus enriching the knowledge base and aiding in the better understanding of Himalayan earthquakes and their effects.

4. BUILT ENVIRONMENT LOSSES

Performance of the built environment and the damage sustained by various types of structures in Abbottabad and Balakot in NWFP, and Muzaffarabad in AJK are discussed in this section. The assessment of structural performance in other locations visited by the team will be presented in the detailed reconnaissance report to be issued from the MAE Center, alongside back-analysis of buildings and bridges in the affected region. The systems considered in this section are primarily, (a) residential buildings, (b) hospital and school buildings, (c) road networks, and (d) bridges. Attention is primarily focused on the construction practice prevalent in the area in each of the categories above, and the common causes of failures observed. It is emphasized that the general observations given below are based on visual inspection with no detailed analysis or formal assessment. They should therefore be taken as preliminary and awaiting further studies and confirmation. A detailed structural damage commentary is also given by the University of Engineering and Technology, Peshawar (UET, 2005).

4.1 RESIDENTIAL BUILDINGS

The October 8, 2005 earthquake left an estimated 2.8 million people in need of shelter. The Government of Pakistan census data indicates that about 439,880 housing units were in the affected area of which 261,990 housing units were completely destroyed, while 177,890 were damaged to various degrees. A distribution of these units in the various districts of the earthquake affected areas, broadly categorized as AJK and NWFP is presented in Table 2.4. Losses to the housing sector represent 84 percent of the total housing stock in the affected districts of AJK, and 36 percent of housing stock in the five affected districts of NWFP.

A typical residential house in the affected rural areas has a relatively small footprint of about 400 sq. ft. of living space, and consists of one or two main rooms, a veranda and a bath and a kitchen which may not be attached. A *Katcha* (non-permanent) house (Figure 4.1) has mud or stone rubble walls with a flat thatch/mud roof supported on timber beams to support heavy mud insulation and snow load. A *Pucca* (permanent) house (Figure 4.2) typically has stone rubble or fired brick masonry walls with cement-sand mortar and a low-pitched sheet metal or reinforced concrete (RC) flat slab roof. The main cause of collapse of both types is the heavy weight of the roof which attracts large inertia forces. The slender unreinforced walls without adequate connectivity to the roof could hardly withstand these inertial forces, often experiencing out of plane failure and collapsing under the weight of the roof. Since a thick roof is essential for insulation in the hostile winter season, any alteration in local construction practice should take into account needs other than seismic design. In relatively more accessible small towns, the use of masonry blocks with a reinforced concrete slab has become increasingly popular. One could also notice reinforced concrete frames with infill walls in mid to large size towns such as Balakot and Muzaffarabd. While many of such semi-engineered buildings completely collapsed or suffered serious damage, the others survived the earthquake with relatively small damage. The nature of the damage points to the usual culprits of poor quality construction, deficient detailing, and lack of seismic consideration.

Figure 4.1 Collapsed Kacha house

Figure 4.2 Destroyed Pucca house

According to AJK Government, 115,211 buildings in Muzaffarabad completely collapsed which constitutes 63% of the collapsed buildings in AJK. Figure 4.3 shows an interior street in the Medina Market which was the main shopping area in Muzaffarabad, the capital city of AJK. As shown in Figure 4.4, poor construction practices, use of smooth reinforcing bars, lack of continuity and proper detailing, and insufficient stirrups for confinement resulted in severe structural damage. Figure 4.5 shows an example of housing units that were made of plastered brick walls and concrete slabs. Old construction mixed with the new and the use of different materials in the same building was commonly observable. Pounding of the adjacent buildings, water tanks at the roof, out-of-plane failure of unreinforced masonry infills, and drastic stiffness discontinuities all contributed to failures of a large number of inner-town buildings in Muzaffarabad.

Figure 4.3 An interior street in Madina Market, Muzaffarabad.

(a) Overview of Madina Market (b) Interior street (c) Failure of Beam-column joint

Figure 4.4 Damage in Madina Market, Muzaffarabad

Figure 4.5 Typical old urban and rural housing units made of brick walls and concrete slabs, Muzaffarabad.

In Balakot several hotels and an entire string of shopping plazas along the main road collapsed or suffered severe damage. Figure 4.6 shows collapsed first story of these two-story plazas. It is clear from the failure mechanisms that these buildings were designed primarily for gravity loads with little consideration for lateral forces. As in Muzaffarabad, poor construction practices manifested in cold joints, lack of structural continuity, poor quality concrete, and first soft story appear to be the most common causes of these building failures.

Figure 4.7 shows the total destruction of an entire community on a small hill just behind the main road in Balakot, where several hundred RC and masonry buildings collapsed. Pending further investigation, the damage is likely to be associated with intense shaking due to ridge effect. Depending on the ridge geometry, ridges amplify the periods corresponding to their own vibration modes, as well as their energy focusing effects.

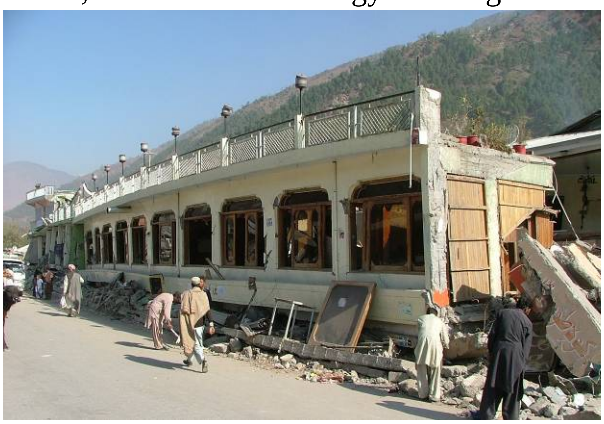



Figure 4.6 Structural failures due to soft story along main street in Balakot

(a) overview of the collapse area on the hill in Balakot

(b) Balakot hill (c) Cold joint and use of undeformed bars

Figure 4.7 Collapse of an entire community on a hill in Balakot

4.2 Hospitals and School Buildings

Estimates of damage to education infrastructure (WB-ADB, 2005) indicate about 7,669 schools were affected, ranging from primary schools to institutions of higher education. These include both government- and privately-owned schools. The damage to public health sector has also been widespread with about 574 health facilities partially or fully damaged (WB-ADB, 2005).

Figure 4.8 (a,b) show the front view and the back views of the Combined Military Hospital (CMH) Hospital in Muzaffarabad. This was a case of soft first story and short column failure with strong axes of all columns aligned in one direction only. The first floor was used as car park and is therefore of an open plan, leading to concentration of the deformation demand on the soft story. A peculiar feature of this building that contributed to its failure is that the right wing had a full basement, while the left-wing had a half-basement with the ground slab constraining the lateral deformation of the basement columns. The right wing which was thus more flexible experienced collapse of the first story. Figure 4.9 (a-c) shows the failure of the beam-column connection, failure of the basement columns, and the details of the transverse reinforcement that lacked confinement, respectively. It should be noted that this hospital building is a good example of a reasonably well-designed and constructed reinforced concrete building. However, several violations of the basic seismic design principles regarding lateral stiffness, flexible first story, and beam-to-column connection details precipitated the extensive damage.

Figure 4.10 shows the punching of a column through the roof slab, and collapse of a hotel building, respectively. Figure 4.11 and Figure 4.12 show the collapse of urban school buildings with a typical out-of-plane failure of unreinforced masonry walls.

Figure 4.8 (a,b). The front and the back views of the Combined Military Hospital (CMH) in Muzaffarabad.

Figure 4.9 (a) Failure of the beam-column connection, (b) failure of the ground floor columns, and (c) the details of the transverse reinforcement, CMH Muzaffarabad

Figure 4.10 (a) Punching failure of the slab in CMH Hospital. (b) Failure of a Hotel Building in Muzaffarabad.

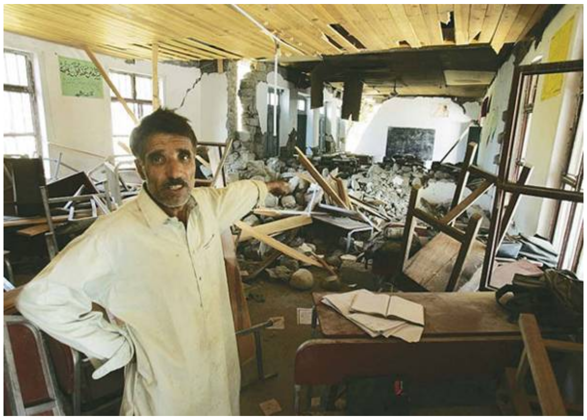


Figure 4.11 Failure of an Urban School Building

Figure 4.12 Collapse of a Secondary school

4.3 ROADS AND BRIDGE STRUCTURES

Damage to the mountainous roads is largely due to landslides precipitated by the earthquake, as described in more detail in subsequent sections of this report. Figure 4.13 (a,b) show the Balakot Bridge on the Kunhar River which was knocked off its bearing supports. Lack of lateral restraints allowed sliding of the bridge that resulted in one outer girder hanging freely (Figure 4.14 a), and other girders left with minimal bearing over their supports (Figure 4.14 b). Preliminary analysis of the bridge indicates that vertical motion may have played a significant role in reducing the vertical force on the bearings, leading to the large observed lateral displacement. Further detailed analysis will be included in the MAE Center full report. Figure 4.15 shows a Muzaffarabad bridge that also lacked lateral restraints, and was shifted from its supports. Figure 4.16 shows a simply supported bridge over a culvert in the epicentral zone where one of the abutments moved more than 8 feet with respect to the other.

Figure 4.13 (a, b). Balakot bridge that lacked lateral constraint leading to sliding on its bearing supports.

Figure 4.14 (a,b). Left girder is hanging free, remaining girders have just 2 inch bearing left, Balakot Bridge

Figure 4.15 Lateral sliding of the Balakot Bridge.

Figure 4.16 Failure of Bridge abutments.

Bridges along Murree to Muzaffarabad route (Figure 4.17) suffered minor damages such as crushing at expansion joint and abutment due to inadequate expansion/seismic gaps between deck segments. Suspension bridges because of their compliant characteristics experienced relatively little damage. A suspension bridge to the north of Muzaffarabad however completely collapsed as land slides toppled the suspension towers as shown in Figure 4.19.

Figure 4.17 Bridges along Murree to Muzaffarabad route, inspect by the MCRU Team

(a) Abutment (b) Expansion joint

Figure 4.18 Observed damage of bridge at Murree to Muzafarabad

Figure 4.19 Collapsed suspension bridge due to land-sliding, North of Muzaffarabad.

5. GEOTECHNICAL EFFECTS

The MCRU team traveled along the southern Himalayan foothills of Hazara consisting of the Abbottabad and Hazara formations of Cambrian age. The Abbottabad formation extends from the Tarbela area in the west through Abbottabad to Muzaffarabad and Balakot in the east and northeast (Kazmi and Qasim, 1997). The Abbottabad group is formed by a thick dolomite/limestone/marble sequence with quartzitic sandstone layers as well as shale and siltstone. The area is mountainous and is dominated by steep terrain. The city of Muzaffarabad and the town of Balakot lie in part within the alluvial valleys of two major rivers, the Jhelum and Kunhar Rivers respectively. From a geotechnical perspective the most dominant ground failure mode observed throughout the earthquake zone is land-sliding and slope instability. The team did not observe first hand evidence of liquefaction or related effects such as lateral spreading and loss of foundation bearing on level ground. However, in meetings with some officials it was noted that there have been cases where "people came out over the roof of a structure, as the entire stories got buried". We continue to look for evidence of liquefaction as this can be used in the estimate of the level of ground shaking. The following sections highlight the preliminary observations of the site visit team.

5.1 GROUND RUPTURE

The causative fault for this earthquake appears to be a blind thrust fault and thus no surface manifestation of fault rupture has been hitherto identified in spite of several teams working in the field. The MCRU team received secondary reports about evidence of surface rupture. This issue remains to be resolved after detailed field investigations by others. It remains unlikely that a confirmed manifestation of the fault rupture will be identified after two months of investigations by land and air, and after the anticipated severe weather.

5.2 LANDSLIDES AND SLOPE INSTABILITY

Land-sliding and critical slope stability was a multi-scale problem that ranged from limited sloughing of surficial nature to a scale that encompassed entire mountain sides. The land-sliding problem in the mountains of AJK and NWFP has similarities to land-sliding that occurred in the mountains of Central Taiwan due to the 1999 Chi-Chi earthquake. Figure 5.1 shows a large scale landslide in the Neela Dandi Mountain to the north of Muzaffarabad. The satellite image shows that the landslide blocked the Jhelum River but was rapidly breached. The landslide debris consists of shale, limestone and dolomite. Most landslides appear to be in a meta-stable state and can be readily activated due to aftershocks or rain. Landslide hazard remains high throughout the affected areas.

Elsewhere a landslide referred to as the Dandbeh Landslide has blocked tributaries of the Jelhum River (Crone, 2005) and as illustrated in Figure 5.2. Lakes are developing behind these landslides and can potentially result in sudden and significant inundation of areas downstream if the earth dams are breached. These lakes will require careful monitoring to avoid potentially adverse impacts downstream.

(a) Satellite image

Figure 5.1 Extensive Landsliding in Neela Dandi Mountain, north of Muzaffarabad.

Figure 5.2 Development of two lakes south of Muzaffarabad along a tributaries of the Jhelum River due to land-sliding, Dandbeh Landslide, Photo Courtesy of A. Crone, USGS and Digital Globe QucikBird II –Natural Color-Oct 27, 2005.

5.3 FOUNDATIONS

Permanent ground deformations due to land-sliding undermined the foundations of many structures including buildings and bridges and resulted in extensive damage. Figure 5.3 shows wide spread damage at Nisar Camp north of Muzaffarabad where over 300 structures were severely damaged or destroyed along a ridge. Cracks are clearly visible along the edges of the ridge as slopes along the edges have displaced laterally. This type of permanent ground deformations due to land-sliding is in part responsible for the widespread damage in Balakot as shown in Figure 5.4 and Figure 5.5.

Figure 5.3 Loss of bearing and complete collapse due to land-sliding and ground slumping long a hill edge, north of Muzaffarabad. Notice the ground cracks.

Figure 5.4 Collapsed structures along hillside in Balakot, note also blocked road due to land-sliding.

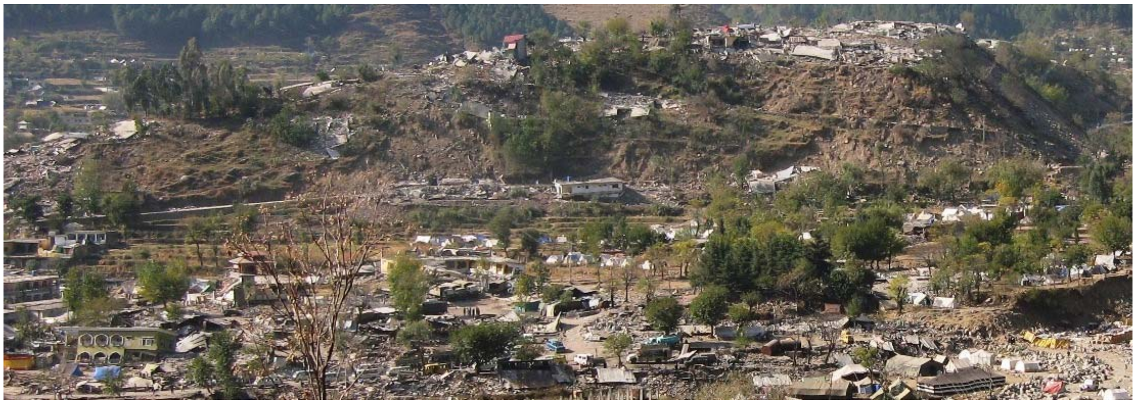
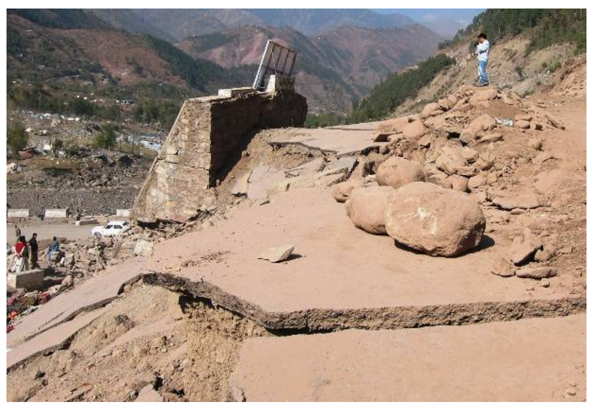


Figure 5.5 Collapsed structures along ridge in Balakot, note land-sliding along the rims.

5.4 RETAINING WALLS AND BRIDGE ABUTMENTS

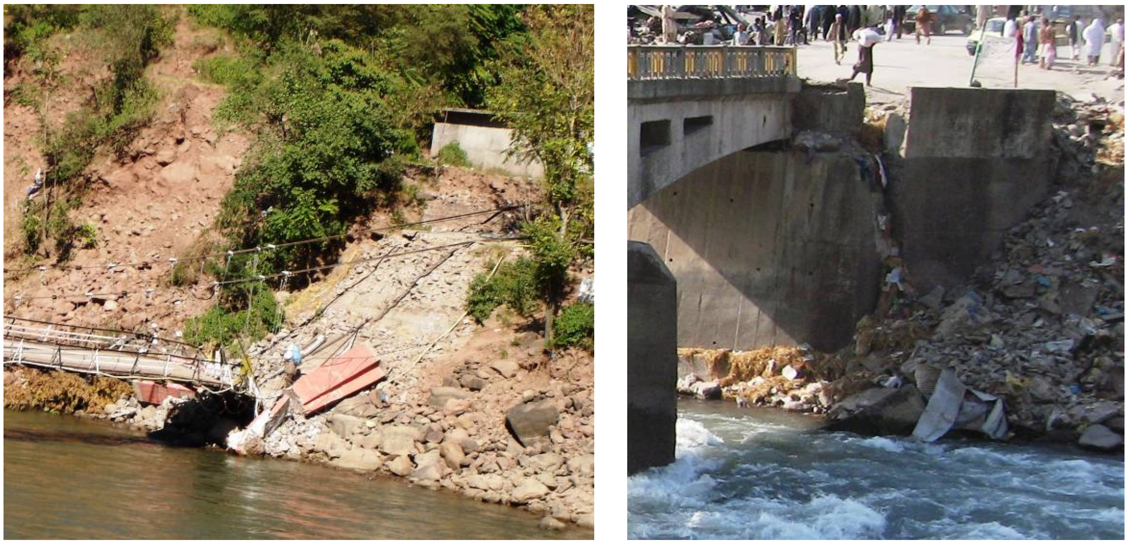
Retaining structures used to support the ground along hillside experienced significant damage throughout the investigated area. In areas where squat walls are used, Figure 5.6, landslide debris overtopped these walls sometimes resulting in damage due to impact of large boulders. In Balakot, a gravity retaining wall was severely damaged due to massive ground deformations associated with land-sliding. Bridge abutments were similarly affected as illustrated in Figure 5.7.

(a)



(b)

Figure 5.6 Damage to retaining walls: (a) Landslide debris overtopping a short retaining wall that remains intact, road south of Muzaffarabad (b) Failure of a gravity retaining wall, Balakot.



(a) (b)

Figure 5.7 Damage to bridge abutments: (a) Collapsed pier/abutment of a suspension bridge, Pushee, Jhelum River, courtesy of S. Saeed, (b) sheared wing-wall for bridge abutment in Balakot.

5.5 ROADS

The road network throughout the earthquake zone suffered severe damage primarily due to land-sliding. Detailed road-by-road assessment is included in report by National Highway Authority, Pakistan (2005). Figure 5.8 shows that the roadway practically disappeared after the earthquake and had to be cleared and realigned. The shown road was paved prior to the earthquake and is now has merely a gravel top layer.

Figure 5.8 Extensive land-sliding along road north of Muzaffarabad leading to Ghori and points beyond.

Along the roads leading to Balakot and Muzaffarabad there was ample evidence of cleared landslides that blocked these roads. The occurrence of these surficial landslides along the rather steep slopes is not unexpected. Figure 5.9 shows a close-up of typical damage to a paved roadway. Numerous transverse and longitudinal road ruptures were observed in the affected area. Figure 5.10 indicates that the measured horizontal and vertical movements of road ruptures were about 30 cm.

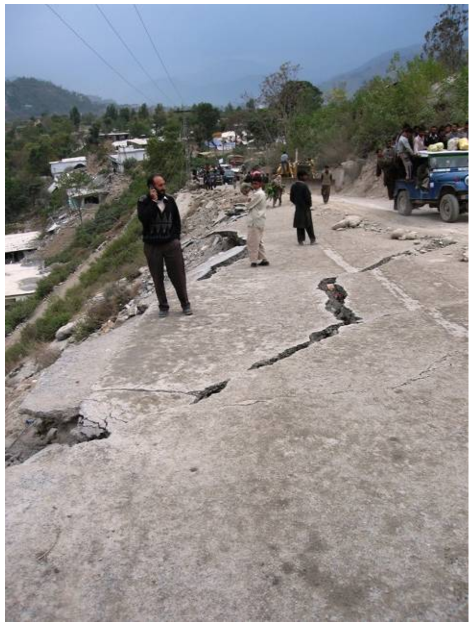


Figure 5.9 Cracked roadway due to land-sliding, north of Muzaffarabad.

(a) Road rupture

(b) Horizontal movement

(c) Vertical Movement

Figure 5.10 Observed road ruptures, north of Muzaffarabad

5.6 Tunnels

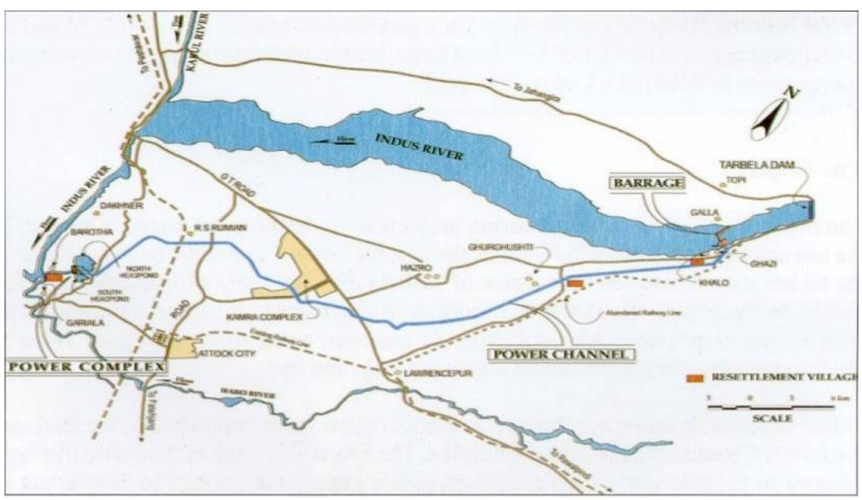
Only one tunnel was encountered along the road between Murree and Muzaffarabad. The tunnel was originally used for northbound traffic while a bypass road along the side of the hill was used for southbound traffic, Figure 5.11. The bypass road was lost due to land-sliding in a predominantly colluvium slope. The tunnel portals were blocked due to land-sliding as well. The tunnel was lined with unreinforced masonry that appears to have remained intact starting from the south portal for about 2/3 of the tunnel length. The northern portion of the tunnel was unlined. It was not readily apparent whether the lining collapsed, or the tunnel was originally unlined.

(a) looking south (b) looking north

Figure 5.11 Land-sliding in colluvium, blocked rock, tunnel relatively intact, South of Muzaffarabad

5.7 DAMS

The Tarbela Dam is the largest earth-filled dam in the world 469 feet high and 2264 feet wide at the base. Shaking was felt at the dam, but no damage was reported, though there were reports of development of waves in the impounded lake. Peak ground accelerations from accelerograph records reported (Khan, 2005) at Tarbela and the related Barotha Power Complex are given in Section 3.3.



(a) Location map of Tarbela Dam and Barotha Power Complex

(b) Tarbel Dam

(c) Barotha Power Complex

Figure 5.12 Tarbela Dam and Barotha Power complex (http://www.infopak.gov.pk/water_reserves/ghazi-barotha.htm)

6. SOCIAL AND ECONOMIC CONSEQUENCES

6.1 IMPACT ON EDUCATION

The estimated damage to education infrastructure is about US$335 million (Rs. 19.9 billion; WB-ADB, 2005). About 7,669 schools were affected, ranging from primary schools to institutions of higher education and including both government owned and privately-owned schools (Table 6.1). Approximately 5,690 of the damaged schools are primary and middle schools. About half of the damaged school structures collapsed or are beyond repair and will need to be rebuilt. In addition to damages to educational institutions and offices, the education sector has also experienced severe human losses, including students, school teachers, and staff. According to preliminary estimates, about 18,095 students and 853 teachers and educational staff died across NWFP and AJK. The deaths of teachers represent not only losses to the teaching force, but also a loss of government investment in teacher capacity development through training.

Table 6.1 Summary of Damaged Institutions by District Rural/Urban and Male/Female Primary through Higher Secondary (WB-ADB, 2005)

District	Rural			Urban				Grand Total
	Boys	Girls	Total	Boys	Girls	Private	Total	
AJK								
a. *Fully Damaged*								
MZD & Neelum	735	521	1,256	14	25	224	263	1,519
Bagh	388	312	700	3	4	105	112	812
Poonch	237	280	517	11	12	115	138	655
Total	**1,360**	**1,113**	**2,473**	**28**	**41**	**444**	**513**	**2,986**
b. *Partially Damaged Damaged*								
MZD & Neelum	104	73	177	2	3	5	10	187
Bagh	45	37	82	-	1	2	3	85
Poonch	109	129	239	5	6	18	29	268
Total	**258**	**239**	**498**	**7**	**10**	**25**	**42**	**540**
NWFP								
a. *Fully Damaged*								
Abbottabad	133	76	209	7	3	76	86	295
Batagram	157	63	220	-	1	47	48	268
Kohistan	103	17	120	-	1	33	34	154
Mansehra	459	262	721	12	10	192	214	935
Shangla	118	45	163	1	0	42	43	206
Total	**970**	**463**	**1,433**	**20**	**15**	**390**	**425**	**1,858**
b. Partially Damaged Damaged								
Abbottabad	332	190	522	18	8	188	214	736
Batagram	105	42	147	-	1	32	33	180
Kohistan	215	35	250	-	1	69	70	320
Mansehra	306	175	481	8	7	128	143	624
Shangla	142	54	196	1	-	50	51	247
Total	**1,100**	**496**	**1,596**	**27**	**17**	**467**	**511**	**2,107**

The recovery efforts to revive the educational infrastructure are estimated at US$472 million (Rs. 28.1 billion; Table 6.2 reproduced from WB-ADB, 2005). The most urgent requirement of the education system is to resume classes at all levels. This would entail the provision of temporary and semi-permanent alternative learning spaces, the repair of partly damaged schools, the provision of learning materials, the training of teachers to replace those who have perished, and the revival of education administrative structures. These short term measures are estimated to cost Rs. 1.2 billion. Over the medium to long term, destroyed schools will need to be rebuilt. This will involve the construction of new schools with earthquake-resistant design, classrooms, facilities, latrines and water supply, and the provision of learning materials, furniture, and equipment. Partly damaged schools will also need to be repaired and retrofitted, and continued teacher training will be required over the medium term. A substantial number of students in these areas may now have special learning needs that would additionally require new teaching approaches and school design modifications for improved accessibility of the disabled.

Table 6.2 Short and Long Term Needs (WB-ADB, 2005)

	Short-Term	**Medium-to Long-Term w/ Seismic Resist**	**Total**
Schools and Temporary Structures	1,000	23,646	24,646
Materials & Furniture	150	3,051	3,201
Teacher Training	30	60	90
Reconstruction Plan	60	60	120
Administration Buildings	N/A	N/A	
Total	**1,240**	**26,817**	**28,057**

6.2 IMPACT ON HEALTHCARE

The damage to public health sector has been widespread and the WB estimates the loss to be in the amount of US$120 million (Rs. 7.1 billion). The report states that the immediate need is to treat more than 70,000 people with injuries. The earthquake's impact also includes severe damage to health infrastructure and health systems, with 574 health facilities partially or fully damaged. Almost 75% of the first level care facilities have been either fully damaged or have suffered partial damage. The five District Headquarters Hospitals were completely destroyed, and the only tertiary health care facility in the region suffered structural damage. In addition, the smaller health units including Sub-Health Centers and First Aid Posts serving remote small mountainous hamlets have been destroyed. Besides the infrastructure, the majority of medical and office equipment, furniture, drugs and laboratories have been destroyed. In addition, official records, including the Health Management Information System (HMIS) data at the Director General Office in AJK and at the District level have been lost. These losses have resulted in a complete breakdown of the health system and a total disruption of both secondary and primary care service provision.

The reconstruction and recovery cost is estimated at US$303 million (Rs. 18 billion; WB-ADB, 2005), and the suggested strategy is to carry out reconstruction in two overlapping phases. In the short term, the most urgent need is to ensure access to an essential health care package that reduces vulnerabilities and saves lives as the system is revitalized. The immediate focus is on the revitalization of the primary health care system, the provision of services in tented villages and for the newly disabled and psychological care for survivors and health care workers. The above assessment does not include the cost of damage to private health care system and indirect losses due to expenditure on treatment of survivors, public health interventions, loss of health staff and the impact of psychological trauma, which have not been computed.

6.3 SOCIAL IMPACT OF THE EARTHQUAKE

The population and social fabric of the earthquake-hit areas have been seriously affected by the number of casualties. Reports vary but deaths are likely to be in excess of 80,000, injuries over 100,000 and about 2.8 million people are without shelter. These figures may still increase as the more remote of the affected areas are accessed. Women and children made up a large percentage of the victims, as many women were caught unaware in houses when the earthquake struck, and the collapse of school buildings resulted in the deaths of many children, perhaps as high as 50% of the total causalities. Among the injured, many will be permanently disabled due to spinal cord injuries, severe head injuries and injuries to limbs, resulting in a high proportion of amputations. Due to difficulties in access, many victims were not rescued in time for necessary medical attention. Furthermore, the number of permanent disabilities continues to increase, as untreated limb injuries have turned gangrenous and required amputations. In this regards, the reconstruction efforts require the development of mechanisms to provide long term care where needed, as well as support for rehabilitation, employment and skills development for people with disabilities. Reconstruction efforts also need to ensure that rebuilt facilities, especially schools, health facilities, and public offices, are accessible to people with disabilities.

6.4 ECONOMIC IMPACT OF THE EARTHQUAKE

The preliminary estimate of the overall cost associated with the earthquake is approximately US$5.2 billion (WB-ADB, 2005). This includes estimated costs for relief, livelihood support for victims, and reconstruction efforts. Of this amount, the direct damage sustained due to the earthquake total Rs. 135.1 billion (US$2.3 billion), as presented below in Table 6.3. These estimates are based on the book value of the assets. The largest component of this damage is to private housing, which amounts to Rs. 61.2 billion (US$1.03 billion), followed by damage to the transport sector totaling Rs. 20.2 billion (US$340 million), and to the education sector equaling Rs. 19.9 billion (US$335 million). Direct damage to agriculture and livestock is also sizeable, totaling Rs. 12.9 billion (US$218 million). The losses to industry and services amount to Rs. 8.6 billion (US$144 million). The indirect losses resulting from the direct damage are Rs. 34.2 billion (US$576 million).

Table 6.3 Preliminary Estimate of Total Losses and Reconstruction Costs (WB, ADB, 2005))

Sector	Direct Damage (Rs. mill.)	Indirect Losses (Rs. mill.)	Reconstruction Costs* (Rs. mill.)	Reconstruction Costs* (US$ mill.)	Share of Total Reconst. Costs (%)
1. Social Infrastructure					
Private Housing**	61,220	7,218	92,160	1552	44
Health	7,114	1,378	18,012	303	9
Education	19,920	4,133	28,057	472	13
Environment	12		8,985	151	4
Public administration	2,971	687	4,254	72	2
2. Physical Infrastructure					
Transport***	20,165	4,061	24,699	416	12
Water Supply and Sanitation	1,165		1,900	32	1
Irrigation	324		623	10	0
Energy, power and fuel	744	1,561	2,377	40	1
3. Economic Sectors**					
Agriculture and livestock	12,933	6,770	17,846	300	9
Industry and Services	8,578	8,379	9,178	155	4
4. Total = 1+2+3 (in Rs. Million)	**135,146**	**34,187**	**208,091**	**3,503**	**100**
o/w : Azad Jammu and Kashmir	76,375	17,671	116,625	1,963	56
: North West Frontier Province	56,436	16,516	91,467	1,540	44
o/w : Public Assets	45,795	12,175	82,187	1,384	39
: Private Assets	87,015	22,012	125,904	2,120	61
o/w : Urban Areas	25,789	13,675	46,163	777	22
: Rural Areas	107,021	20,512	161,928	2,726	78

Notes: * Includes cost of reconstruction of both immovable and movable assets and restoration of public services.

** Includes value of household contents such as consumer durables; reconstruction costs exclude replacement of these assets.

*** Includes roads and bridges.

**** Total losses and reconstruction costs in agriculture, industry and services are over and above what is accounted for by the sectors listed above.

7. CLOSURE

The Kashmir earthquake of October 8, 2005 inflicted a heavy toll on lives and livelihoods in a large region in northern Pakistan, Kashmir and even parts of northern India. It is in an active tectonic region where the Indian plate subducts under the Asian plate, creating an arc of high seismicity that was responsible for major earthquakes in the past. Whilst the earthquake had a magnitude of 7.6, the capability of the faults in the Himalayan region is for earthquakes of magnitude > 8.0, of which several are expected in the future. This Quicklook report gives a review of the damage and other consequences of the earthquake directly from the observations of the MAE Center-Rice University Team, as well as summarizes selected previous reports.

Whereas definitive recommendations await further in-depth studies and interactions with authorities and researchers in Pakistan, the following preliminary recommendations for priorities and action are offered at this early stage:

Hazard

- Development of a national instrumentation program to deploy, operate and maintain a dense network of digital acceleration recording stations that covers not only the northern regions but the entire Pakistani territory, as well as a mandatory requirement for instrumenting all new projects with a minimum of sensing stations for the collection of vital response data.
- Development of a micro-zonation program for areas of (i) special soil conditions, (ii) in the vicinity of large steep slopes, and (iii) on significant ridges.
- Undertaking comprehensive seismic risk assessment studies using probabilistic hazard analysis (PSHA), deterministic studies for critical sites (DSHA), and time-dependent seismic hazard assessment, leading to nationally accepted hazard maps.

Urban and Rural Planning

- Development of a comprehensive multi-scale land use management policy and grand plan to gradually move population, business and infrastructure systems away from regions of the highest exposure to natural disasters such as earthquakes and floods.
- Clearing congested old town centers gradually to widen streets and provide access to emergency services, and to construct using modern techniques, materials and codes of practice.
- Implementation of planning permit guidelines to influence characteristics of buildings and bridges to reduce amplification effects taking into account site conditions and topography.
- Development or adoption of a loss assessment software tool that is used in regional and national scenario loss assessments for the purposes of planning of response, stockpiling of required equipment and recruitment of necessary personnel.

Design and Construction

- Development of two levels of codes for design, one for detailed design of important facilities and large civil infrastructure projects, based on the latest technologies and international experience adapted to Pakistan, and the second as a set of ‘deemed-to-satisfy’ codes using local practice, regional languages, pictorial-visual presentations and no calculation requirements, for small family residences and similar structures, using indigenous materials.
- Implementation of hierarchical, self-monitored, strict construction authorization procedures. This should include continuous control of all construction and concurrent penalties on defaulting, non-conforming and random housing.

- Mandating earthquake resistant design according to the published codes.
- Development of codes for seismic resistance of infrastructure and lifeline systems.
- Increasing the use of tunnels to reduce the impact of earthquakes on the transportation network in the mountainous regions.
- Use of the most advanced tunnel design and construction practice to increase the reliability of tunnels as vital components of the transportation systems.

Social Impact Reduction

- Development of special policies for design and construction for critical facilities, primarily schools, hospitals, emergency response centers, power generation, water supply, gas supply and similar facilities critical to the operation of a complex societal system.
- Mandating of disabled access provisions in all civil infrastructure works.
- Planning of disabled support and rehabilitation centers taking into account the current distribution of residences of the large population of disabled citizens from the Kashmir earthquake.
- Development of medium and long-term plan for widowed women and orphaned children in terms of a continuous and accessible support structure for rehabilitation, education and integration in other families.

Legislation

- Backing up all the above by rigorous legislative structures and clear frameworks for adherence.
- Legislating for a complete and comprehensive framework of emergency management professionals at the local, regional and national levels, and a clear reporting mechanism, alongside a tiered emergency preparedness plan.
- Establishing a 'Disaster Fund' that is used to provide emergency relief, and that is funded by a modest tax on new projects. Such funds have precedence and experience should be gained from other countries on this issue.

The above list is not comprehensive and is subject to further refinement and articulation as more information becomes available and the needs are better defined. The investigative work continues at the MAE Center and Rice University and a detailed report including several case studies will be issued in due course.

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APPENDICES

A.1 FIELD MISSION MEMBERS AND SPECIALIZATION

Name	Technical Role	Logistical Role
Ahmad Jan Durrani	(i) structural earthquake engineering; (ii) concrete structures	Team Leader
Amr Salah Elnashai	(i) structural earthquake engineering; (ii) strong-motion effects	Technical Leader
Arif Masud	(i) structural earthquake engineering; (ii) wave propagation	Communications Coordinator in Pakistan
Youssef Hashash	(i) geotechnical earthquake engineering; (ii) engineering seismology	Communications Coordinator in the USA
Sung Jig Kim	(i) structural earthquake engineering; (ii) detailed back-analysis	Documentation and Reporting Coordinator

A.2 PAKISTANI HOST ORGANIZATIONS

1. Higher Education Commission (HEC)
2. Army Corps of Engineers
3. Lahore University of Management Sciences (LUMS)
4. Halcrow Pakistan
5. University of Engineering and Technology, Peshawar (UET)
6. National Engineering Services of Pakistan (NESPAK)
7. Water and Power Development Authority (WAPDA)
8. National University of Sciences and Technology (NUST)
9. University of Engineering and Technology, Lahore
10. Government College University, Lahore
11. University of the Punjab
12. Geological Survey of Pakistan
13. Public Works Department, Highways, AJK
14. Pakistan Meteorological Department
15. Pakistan Engineering Council
16. National Highway Authority

A.3 ITINERARY AND ROUTE

November 5-15 2005, see also figures on next pages.

Date		Description
Nov 5/6	Early AM	Arrival in Lahore (except A.Masud)
Nov 6	AM	Internal meeting
	PM	Meeting at LUMS (Lahore University of Management Science) Meeting at HEC-Lahore (High Education Commission) with University of Punjab and University of Engineering and Technology, Lahore
Nov 7	AM	Meeting with NESPAK (National Engineering Services – Pakistan) Fly to Islamabad
	PM	Meeting at HEC-Islamabad
Nov 8	AM	Meeting at Pakistan Geologic Survey
	PM	Depart for Earthquake Zone to Abbottabad, Mansera and Hazara University
Nov 9	AM	Survey Damage from Abbottabad to Balakot,
	PM	Balakot, Drive through Gheri Habibullah Khan, Muzaffarabad, to Murree/ PC Burbhan
Nov 10	AM	Survey damage from Murree to Muzaffarabad
	PM	Meeting with Army Corps of Engineers in Muzaffarabad, and further damage survey Return to Islamabad
Nov 11	AM	Meeting at: • NHA (National Highway Authority) with lecture and questions and answer session • Meeting with Army Engineers
	PM	• Meeting with NESPAK • Meeting with Pakistan Engineering Council, and Army Corp of Engineers
Nov 12	AM	Team Returns to US, except A. Masud Meeting with rector-NUST
	PM	• Visit Margala Towers • Meeting with Planning Division • Meeting with Army Engineers
Nov 13		Meeting with HEC
Nov 14	PM	Meeting with GIK and WAPDA
Nov 15	AM	A. Masud returns to US

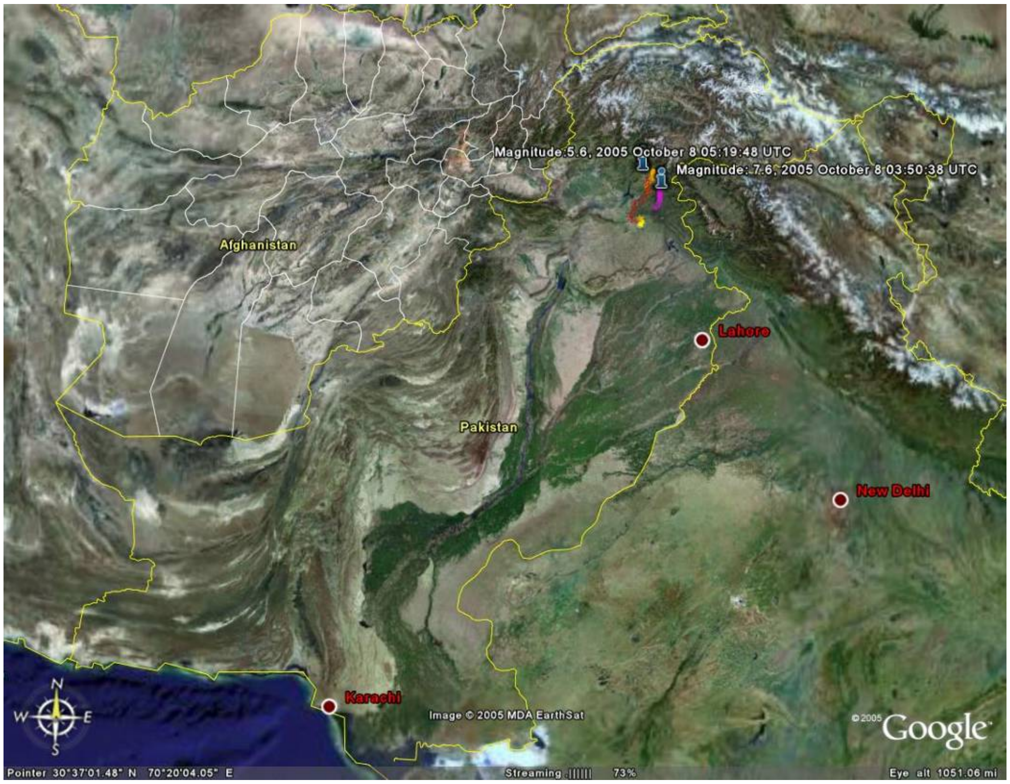

Figure A.1 General map of Pakistan showing major cities, international borders and earthquake epicenter

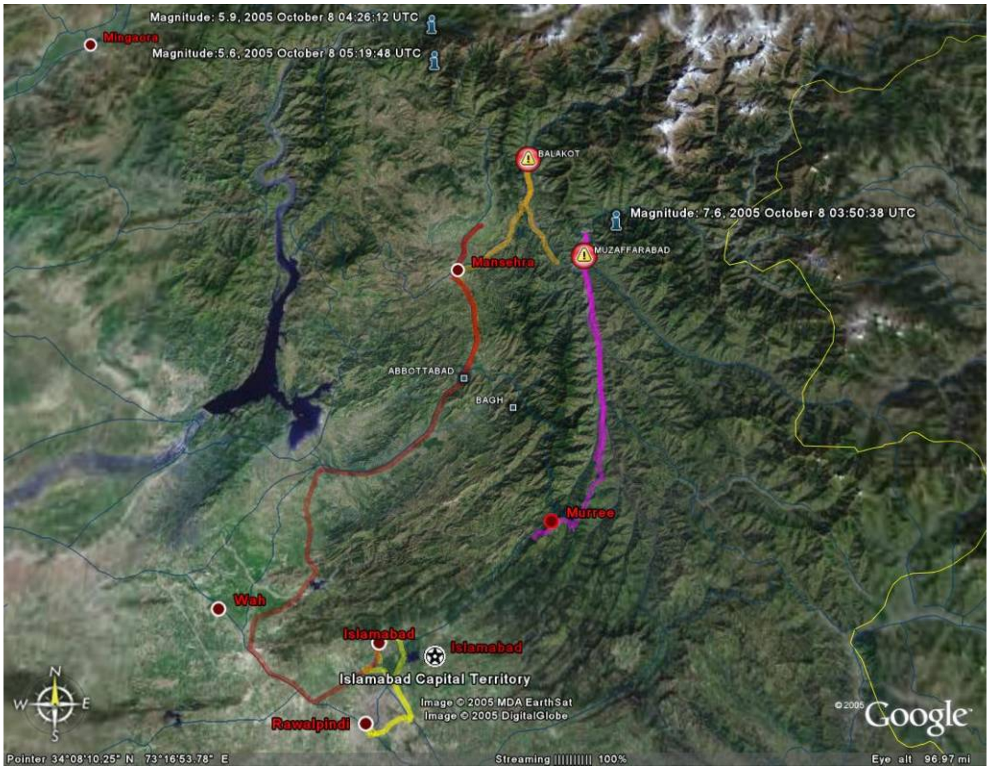

Figure A.2 Map of northern Pakistan showing major cities and routes visited by MCRU team. thick color lines represent gps logs of the routes.

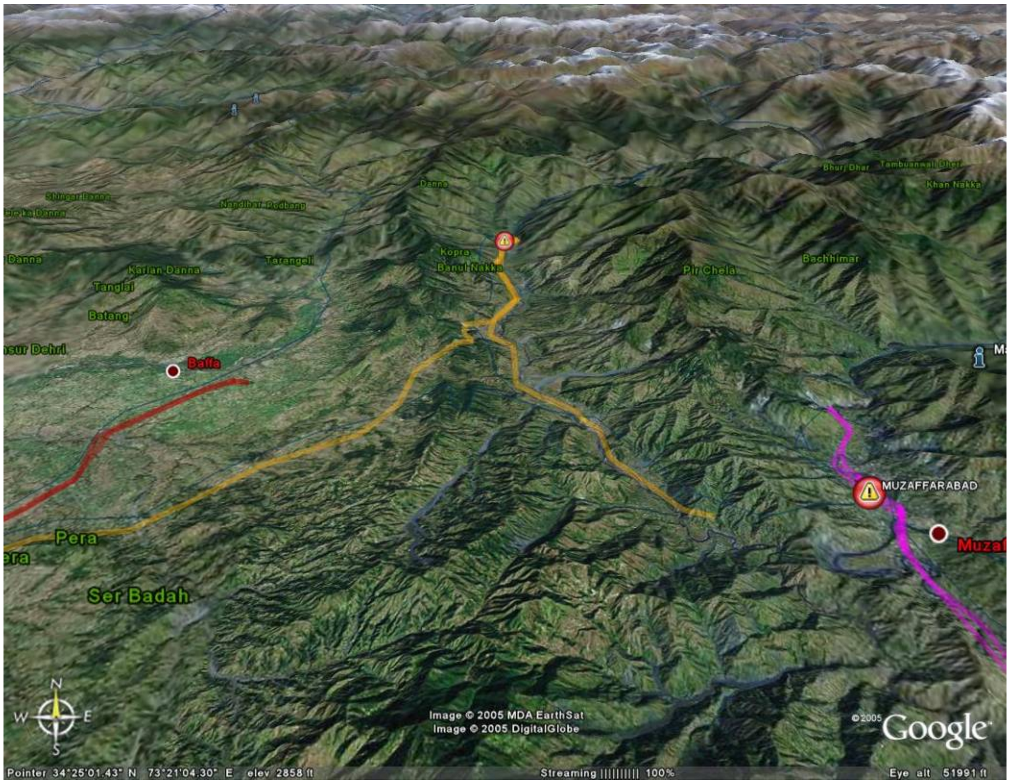

Figure A.3 Close up view of the areas visited with the heaviest damage

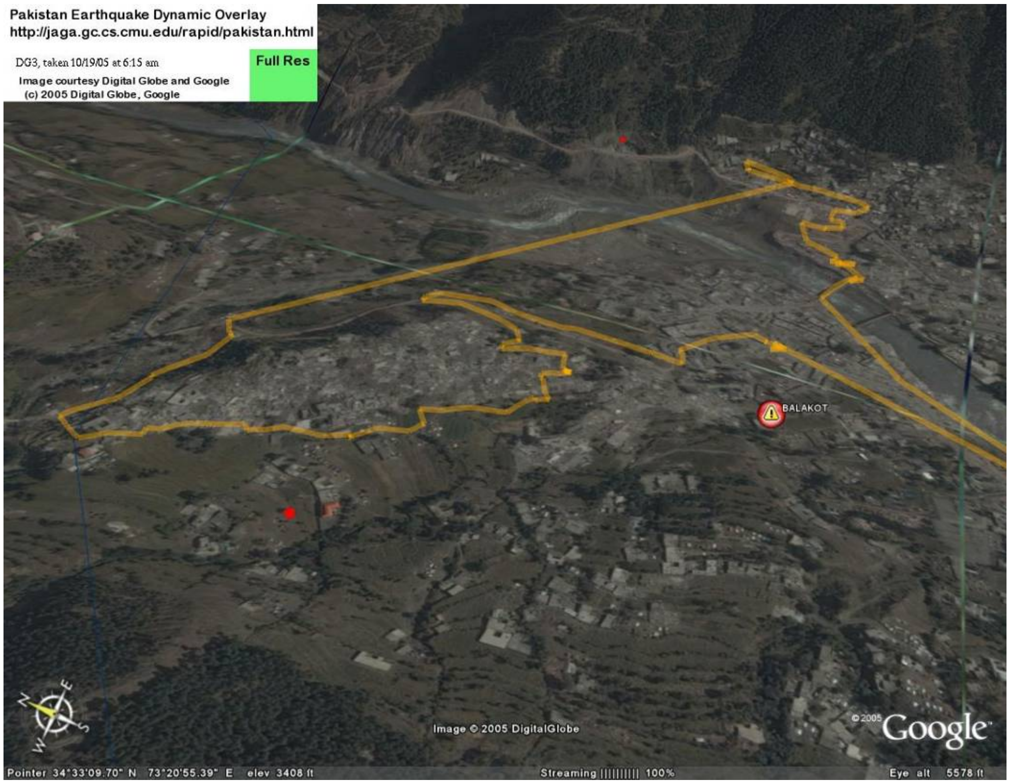

Figure A.4 Close up satellite view of Balakot and the route taken by the MCRU team shown in yellow.

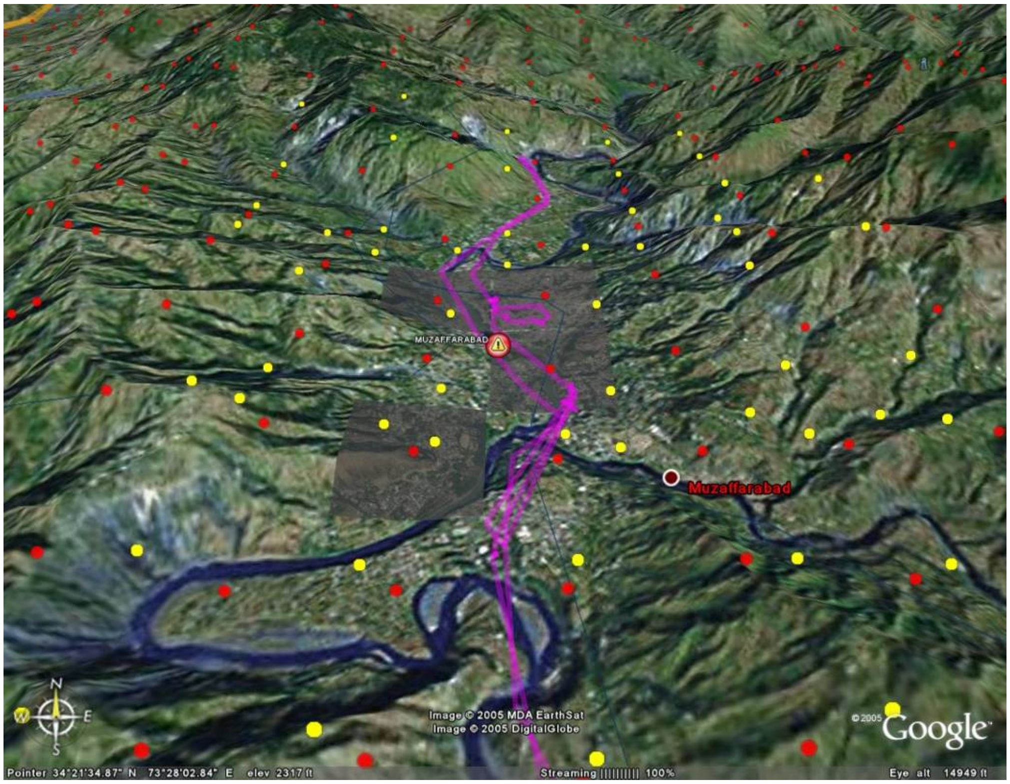

Figure A.5 Close up view of areas visited in Muzaffarabad. Pink line